THE UNIVERSITY OF ALBERTA

SOME NUMERICAL STUDIES IN THE THEORY OF NUMBERS

by

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ABSTRACT

There are many conjectures in the theory of numbers for which numerical verification of special cases is easily obtained. With the development of more advanced computing machinery and additional number theoretic techniques, it is possible to extend such numerical verification considerably. In this thesis, various unsolved conjectures for which the previously known results depend mainly on hand calculations are considered from this point of view. Methods involving both numerical and elementary number theoretic techniques are developed and used extensively, leading, in all cases, to the extension of known results.

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INTRODUCTION

In Chapter I two problems due to L. Moser are discussed. These consist in determining the solvability of two special diophantine equations involving the binomial coefficients $\binom{2n}{n}$. The non-existence of solutions to these equations is established by a combination of analytic and numerical methods.

In Chapter II a conjecture of P. Erdős involving the primality of the numbers $n-2^k$, $1 \leq k \leq \left[\frac{\log n}{\log 2}\right]$, is considered. A numerical procedure is developed and, from this, restrictions are obtained on the number n.

In Chapter III a sieve process is developed for the purpose of investigating the non-squareness of elements of particular sequences of integers. An I.B.M. 1620 electronic computer is used in the application of this process to the sequences $\{n! + 1\}$, $\{G_n\}$, and $\{T_n\}$, where

$$\sum_{n=0}^{\infty} G_n \frac{x^n}{n!} = e^{e^x - 1} \quad \text{and} \quad \sum_{n=0}^{\infty} T_n \frac{x^n}{n!} = e^{x + \frac{x^2}{2}}.$$

By these means, previous results concerning non-squareness of the elements of these three sequences are extended.

In Chapter IV the following problem is considered: Is it necessary that n be a prime number in order that the congruence

$$\sum_{i=1}^{n-1} i^{n-1} \equiv -1 \pmod{n}$$

hold? The answer to this question is shown to be in the affirmative for all $n \leq 10^{5000}$ by means of a method involving elementary number theoretic techniques and considerable calculation.

CHAPTER I

In this chapter we consider the solvability of two closely related diophantine equations of the form

$$(1.1) \qquad f(a) = f(b)f(c) .$$

P. Erdös, in private communication with L. Moser, provided a sketch of the proof that this equation has at most a finite number of solutions in positive integers when $f(a) = \binom{2a}{a}$. The details and completion of that proof will be given here to show that (1.1), with $f(a) = \binom{2a}{a}$, has no solution in positive integers a, b and c. As is well known, the quantity $\frac{\binom{2a}{a}}{a+1}$ is an integer for integral a. Thus, it is natural to consider the solvability of equation (1.1) for $f(a) = \frac{\binom{2a}{a}}{a+1}$. Using the same method of analysis as applied to the equation $\binom{2a}{a} = \binom{2b}{b}\binom{2c}{c}$, we find, in this case, that (1.1) is unsolvable in positive integers a, b and c, provided $a,b,c \neq 1$. This method fails, however, in the case $f(a) = a!$. W. Sierpiński, [19], notes the two classes of trivial solutions

$$a!! = (a! - 1)!\, a! ,$$
$$a! = a!\, 1!$$

and the non-trivial solution $10! = 7!\, 6!$. It has been conjectured that $(a, b, c) = (10, 7, 6)$ is the only non-trivial solution to the equation $a! = b!\, c!$.

Theorem 1.1.

The diophantine equation

$$\binom{2a}{a} = \binom{2b}{b}\binom{2c}{c}$$

is unsolvable in positive integers a, b, c.

We use the following lemmas:

Lemma 1.1.

If $n! = \prod p^{\alpha}$, the product being taken over all primes p, and $[x]$ denotes the largest integer $\leq x$, then

$$(1.2)\qquad \begin{aligned} \alpha = \alpha_p(n) &= \left[\frac{n}{p}\right] + \left[\frac{n}{p^2}\right] + \left[\frac{n}{p^3}\right] + \dots \\ &= \frac{n - s_p(n)}{p - 1} \quad , \end{aligned}$$

where $s_p(n)$ is the sum of the digits in the representation of n to the base p :

$$n = a_0 + a_1 p + a_2 p^2 + \dots + a_k p^k \cdot (0 \leq a_i < p) ,$$

$$s_p(n) = \sum_{i=0}^{k} a_i \quad .$$

The proof of Lemma 1.1 is due to A. Legendre [12].

Lemma 1.2.

If $\binom{n}{r} = \prod p^{\beta}$ then $p^{\beta} \leq n$.

Proof:

With the same notation as used in Lemma 1.1, we have

$$\beta = \beta_p(n,r) = \alpha_p(n) - \alpha_p(n-r) - \alpha_p(r) .$$

From expression (1.2),

$$\beta_p(n,r) = \sum_{i=1}^{\infty} \left\{ \left[\frac{n}{p^i} \right] - \left[\frac{n-r}{p^i} \right] - \left[\frac{r}{p^i} \right] \right\} .$$

Each term of the above series has value 0 or 1 since

$$\left(\frac{n}{p^i} - 1 \right) - \frac{n-r}{p^i} - \frac{r}{p^i} < \left[\frac{n}{p^i} \right] - \left[\frac{n-r}{p^i} \right] - \left[\frac{r}{p^i} \right] < \frac{n}{p^i} - \left(\frac{n-r}{p^i} - 1 \right) - \left(\frac{r}{p^i} - 1 \right)$$

$$- 1 < \left[\frac{n}{p^i} \right] - \left[\frac{n-r}{p^i} \right] - \left[\frac{r}{p^i} \right] < 2 .$$

If k denotes the integer for which $p^k \leq n$ and $p^{k+1} > n$ then clearly, the number of non-zero terms in the series

$$\sum_{i=1}^{\infty} \left\{ \left[\frac{n}{p^i} \right] - \left[\frac{n-r}{p^i} \right] - \left[\frac{r}{p^i} \right] \right\}$$

is $\leq k$. Thus, $\beta = \beta_p(n,r) \leq k$ and Lemma 1.2 follows.

Lemma 1.3.

For $n \geq 9r$, $\binom{n}{r} > \frac{(21.3)^r}{3r}$.

Proof:

Consider the expression

$$\frac{\binom{9r+9}{r+1}}{\binom{9r}{r}} = \frac{9}{8(r+1)} \frac{(9r+8)(9r+7)\ \dots\ (9r+1)}{(8r+7)(8r+6)\ \dots\ (8r+1)}$$

$$\geq \frac{9}{8} \frac{9r}{(r+1)} \frac{(9r+7)(9r+6)\ \dots\ (9r+1)}{(8r+7)(8r+6)\ \dots\ (8r+1)} .$$

Since $\frac{9r+a}{8r+a} \geq \frac{97}{87}$ for $r \geq 10$ and $a \leq 7$, it follows that

$$\frac{\binom{9r+9}{r+1}}{\binom{9r}{r}} \geq \frac{81}{8} \left(\frac{97}{87}\right)^7 \frac{r}{(r+1)} , \qquad r \geq 10$$

$$\geq 21.36 \frac{r}{(r+1)} .$$

Hence

$$(1.3) \qquad \frac{\binom{9r+9}{r+1}}{\binom{9r}{r}} > \frac{\frac{(21.3)^{r+1}}{3(r+1)}}{\frac{(21.3)^r}{3r}} ,$$

provided $r \geq 10$.

By direct checking, we find

$$\binom{9r}{r} > \frac{(21.3)^r}{3r}$$

for $r = 1, 2, 3, \dots, 10$. This result, together with inequality (1.3), implies

$$\binom{9r}{r} > \frac{(21.3)^r}{3r} ,$$

and the assumption that $n \geq 9r$ then yields

$$\binom{n}{r} \geq \binom{9r}{r} > \frac{(21.3)^r}{3r} .$$

Lemma 1.4.

If $n > 8k$ and $k > 33$, there exists a number in the set of consecutive integers $n, n+1, \ldots, n+k-1$ which has a prime divisor greater than $2k$.

This lemma is seen to be closely related to the well-known theorem of Sylvester and Schur which states:

The product of k consecutive integers, each greater than k, has a prime divisor greater than k.

One of the most elementary proofs of this theorem is supplied by P. Erdös, [5]. We make slight modifications in this proof to establish Lemma 1.4 in the following equivalent form:

If $n \geq 9k$ and $k > 33$, the expression $\binom{n}{k}$ contains a prime factor greater than $2k$.

Proof:

Let us assume that $\binom{n}{k}$ contains no prime factor $> 2k$. If $\binom{n}{k} = \prod p^{\beta}$, there will be at most $\pi(2k)$ distinct primes occurring in this product, where $\pi(x)$, as usual, denotes the number of primes $\leq x$. Thus, by Lemma 1.2,

$$(1.4) \qquad \binom{n}{k} = \prod p^{\beta} \leq n^{\pi(2k)} .$$

J. B. Rosser and L. Schoenfeld, [18], have shown that $\pi(x)$ satisfies the following inequality:

$$(1.5) \qquad \pi(x) < 1.25506 \frac{x}{\log x} \quad , \quad x > 1.$$

Combining expressions (1.4) and (1.5), with $x = 2k$ in (1.5), we obtain

$$\binom{n}{k} < n^{2.51012 \frac{k}{\log 2k}} .$$

Furthermore, since $\binom{n}{k} \geq \left(\frac{n}{k}\right)^k$ for $n \geq k > 0$, it follows that

$$\frac{n}{k} < n^{\frac{2.51012}{\log 2k}} ,$$

and

$$(1.6) \qquad k^{\frac{1}{1-\frac{2.51012}{\log 2k}}} > n .$$

It is shown in [18] that

$$\theta(x) < 1.01624x \quad , \quad x > 0 ,$$

where $\theta(x) = \log \prod_{p \leq x} p$. Thus

$$(1.7) \qquad \prod_{p \leq x} p < (2.763)^x .$$

Let D denote the set of primes p for which $\beta = \beta_p(n,k) = 1$ in the product $\prod p^\beta = \binom{n}{k}$. Our initial assumption, together with (1.7), then implies

$$\prod_D p^\beta < (2.763)^{2k} .$$

By Lemma 1.2, the magnitude of the primes appearing to the power $\beta > 1$

in $\prod p^{\beta}$ must be $\leq \sqrt{n}$. Hence, if C denotes the set of primes p for which $\beta > 1$ in $\prod p^{\beta}$, there will be at most $\pi(\sqrt{n})$ distinct prime factors in $\prod_{C} p^{\beta}$, and

$$\prod_{C} p^{\beta} \leq n^{\pi(\sqrt{n})} .$$

Thus,

$$\binom{n}{k} = \prod_{D} p^{\beta} \prod_{C} p^{\beta} < (2.763)^{2k} \, n^{\pi(\sqrt{n})} .$$

It then follows, from Lemma 1.3, that

$$\frac{(21.3)^{k}}{3k} < (2.763)^{2k} \, n^{\pi(\sqrt{n})} .$$

We now make use of inequality (1.5) with $x = \sqrt{n}$ to obtain, from the above expression,

$$\frac{(21.3)^{k}}{3k} < (2.763)^{2k} \, n^{2.51012 \frac{\sqrt{n}}{\log n}} .$$

Taking logarithms of both sides of this inequality yields

$$k \log\left(\frac{21.3}{(2.763)^{2}}\right) < \log 3k + 2.51012 \sqrt{n} .$$

Further, by inequality (1.6),

$$(1.8) \qquad 1.02574\, k < \log 3k + 2.51012\, k^{\frac{1}{2\left(1-\frac{2.51012}{\log 2k}\right)}} .$$

For the purpose of examining the behaviour of both sides of inequality (1.8), we assume k to be a continuous variable. Taking the derivatives, with respect to k, of both sides of the inequality, we find

$$\frac{d}{dk}(1.02574\, k) > \frac{d}{dk}\left(\log 3k + 2.51012\, k^{\frac{1}{2(1-\frac{2.51012}{\log 2k})}}\right), \quad k \geq 200,$$

and $1.02574\, k > \log 3k + 2.51012\, k^{\frac{1}{2(1-\frac{2.51012}{\log 2k})}}$ for $k = 300$.

Hence, inequality (1.8) and, consequently, our initial assumption are false if $k \geq 300$.

Now, consider k in the range $33 < k < 300$. We saw earlier that if the expression $\binom{n}{k}$ has no prime factor $> 2k$ then

$$(1.9) \qquad k^{\frac{1}{1-\frac{2.51012}{\log 2k}}} > n\,.$$

Without loss of generality, we may assume the continuity of the variable k in extremizing the function $k^{\frac{1}{1-\frac{2.51012}{\log 2k}}}$. We find that

$$\frac{d}{dk}\left(k^{\frac{1}{1-\frac{2.51012}{\log 2k}}}\right) < 0 \quad \text{for} \quad 33 < k \leq 52$$
$$> 0 \quad \text{for} \quad k \geq 53.$$

Thus, from inequality (1.9), the following upper bounds for n are obtained:

$$n < (33)^{\frac{1}{(1-\frac{2.51012}{\log 66})}} < 6{,}140 \quad \text{for} \quad 33 < k \leq 52$$

and

$$n < (300)^{\frac{1}{(1-\frac{2.51012}{\log 600})}} < 11,940 \quad \text{for} \quad 53 \leq k < 300.$$

A reference to the recently published table of K. Appel and J. B. Rosser, [1], shows that the maximum gap between successive primes

(i) under 6,140 is 34 ,

and

(ii) under 11,940 is 36 ;

where the gap between the primes p_n and p_{n+1} is defined as $p_{n+1}-p_n$. From this it follows that the sequence of integers:

$n-k+1,\ n-k+2,\ \ldots,\ n$

contains a prime number $> 8k$ for

(i) $9k \leq n < 6,140 \quad , \quad 33 < k \leq 52$;

and

(ii) $9k \leq n < 11,940 \quad , \quad 53 \leq k < 300$.

Thus our lemma is proved.

The number 33, mentioned in Lemma 1.4, is not necessarily the best lower bound for k but it will suffice for our present purpose. The minimum value of k required for the truth of the lemma could be determined by a combination of direct checking, inequality (1.9) and the use of the following: If p is a prime number > 3 then the existence of a number of the form p, $2p$, $3p$, or $4p$ in the sequence of integers $n, n+1, \ldots, n+k-1$ implies at least one of the numbers in this sequence has a prime factor $> 2k$, provided $n > 8k$.

Proof of Theorem 1.1:

Without loss of generality we may take $a > b \geq c$. Clearly $2b > a$ for equality to occur between $\binom{2a}{a}$ and $\binom{2b}{b}\binom{2c}{c}$, for otherwise, primes in the interval $(2a, a)$ would divide $\binom{2a}{a}$ but not $\binom{2b}{b}\binom{2c}{c}$.

Let $a = b+x$, $\frac{b}{8} \leq x < b$. R. Breusch, [2], has established the existence of a prime in the interval $(\frac{9}{8}b, b)$ for $b \geq 48$. Thus, the interval $(2a, 2b)$ contains a prime which divides $\binom{2a}{a}$ but not $\binom{2b}{b}\binom{2c}{c}$, provided $b \geq 24$.

Consider now the following expression with $0 < x < \frac{b}{8}$,

$$\frac{\binom{2a}{a}}{\binom{2b}{b}} = \frac{\binom{2b+2x}{b+x}}{\binom{2b}{b}}$$

$$= 2^x \frac{(2b+1)(2b+3)\ \ldots\ (2b+2x-1)}{(b+1)(b+2)\ \ldots\ (b+x)} .$$

By Lemma 1.4, the product $(b+1)(b+2)\ \ldots\ (b+x)$ contains a prime divisor $q > 2x$ for $x > 33$; that is, there exists some integer i in the range $1 \leq i \leq x$ such that

$$b + i \equiv 0 \pmod q .$$

As a consequence of the above congruence,

$$2b + 2j - 1 \not\equiv 0 \pmod q \quad \text{for} \quad j = 1, 2, \ldots, x$$

and $(2b+2x-1)(2b+2x-3)\ \ldots\ (2b+3)(2b+1) \not\equiv 0 \pmod q$.

Since the prime q divides the denominator but not the numerator of

the expression

$$2^x \frac{(2b+1)(2b+3)\ \dots\ (2b+2x-1)}{(b+1)(b+2)\ \dots\ (b+x)} = T_x ,$$

it follows that $\dfrac{\binom{2a}{a}}{\binom{2b}{b}}$ cannot be an integer for $\frac{b}{8} > a - b > 33.$

Suppose now that $a-b = x \leq 33,\ b > 8x > 0.$ A rearrangement of the factors in the expression for T_x gives

$$T_x = 2^x \left(\frac{2b+1}{b+x}\right)\left(\frac{2b+3}{b+1}\right) \dots \left(\frac{2b+2x-1}{b+x-1}\right)$$

$$\geq 4^x \left(\frac{2b+1}{2b+2x}\right) .$$

Trivially, $T_x < 4^x$. For $b \geq 42$, T_x must then satisfy the following inequality:

$$(1.10) \qquad 4^x > T_x \geq 4^x \left(\frac{85}{84+2x}\right) .$$

Upon substituting the values 1, 2, 3, 4, 5 for x in (1.10) we find

$$(1.11) \qquad \begin{aligned} 4 &> T_1 > 3.95 \\ 16 &> T_2 > 15.45 \\ 64 &> T_3 > 60.44 \\ 256 &> T_4 > 236.52 \\ 1024 &> T_5 > 925.95 \ . \end{aligned}$$

A comparison of the above inequalities with the values of $\binom{2c}{c}$ for $1 \leq c \leq 7$, namely:

$$\binom{2}{1} = 2 \qquad \binom{6}{3} = 20 \qquad \binom{10}{5} = 252 \qquad \binom{14}{7} = 3,432 ,$$

$$\binom{4}{2} = 6 \qquad \binom{8}{4} = 70 \qquad \binom{12}{6} = 924$$

illustrates that $T_x \neq \binom{2c}{c}$ for $x = 1, 2, 3, 5$. Also, if equality is to hold between T_4 and $\binom{2c}{c}$ then c must be 5. Now, for $(b+1)(b+2) \ldots (b+x) = 2^{a_1} \cdot 3^{a_2} \cdot 5^{a_3} \ldots, \ a_i \geq 0$, we have, using the notation of Lemma 1.1,

$$a_i \geq \left[\frac{x}{2} \right] + \left[\frac{x}{2^2} \right] + \ldots = \alpha_2(x) .$$

The highest power of 2 which divides the quantity

$$T_x = 2^x \frac{(2b+1)(2b+3) \ldots (2b+2x-1)}{(b+1)(b+2) \ldots (b+x)} \text{ is then } 2^d, \text{ where } d \leq x-\alpha_2(x).$$

From Lemma 1.1, $\alpha_2(x) = x-s_2(x)$, so that placing $x = 4$ gives $d \leq 1$. Since 2^2 is a divisor of $\binom{10}{5}$ but not of T_4, it follows that $T_4 \neq \binom{10}{5}$. Thus $T_x \neq \binom{2c}{c}$ for $1 \leq x \leq 5$.

From the recurrence relations:

$$T_x = \frac{2(2b+2x-1)}{(b+x)} T_{x-1}$$

and

$$\binom{2x+2}{x+1} = \frac{2(2x+1)}{(x+1)} \binom{2x}{x} ,$$

and the inequality $\binom{14}{7} > T_5 > \binom{12}{6}$, we find that $T_x > \binom{2x+2}{x+1}$ for $x \geq 5$. Furthermore, it is easy to show by induction that $\binom{2x}{x} > \dfrac{4^x}{2\sqrt{x}}$, $x > 1$. Hence $\binom{2x+4}{x+2} > 4^x$ provided $x < 64$.

The left-hand side of inequality (1.10) and the preceding results then imply

$$\binom{2x+4}{x+2} > T_x > \binom{2x+2}{x+1}$$

for $5 \leq x < 64$.

In summary, the equation

$$(1.12) \qquad \binom{2a}{a} = \binom{2b}{b}\binom{2c}{c} \quad , \quad a > b \geq c$$

is unsolvable in positive integers $a, b, c,$ if

(i) $b \geq 24$ with $2b > a \geq \frac{9}{8} b$

or

(ii) $b \geq 42$ with $\frac{9}{8} b > a > b$.

Thus, in order to establish Theorem 1.1, it suffices to show that (1.12) is unsolvable for $2a < 96$. This can easily be done with the aid of Table [I] of the Appendix, which gives the prime factorization of the numbers $\binom{2a}{a}$ for $a \leq 47$. The following example illustrates the procedure used: Let $a = 18$. Table [I] shows that 31 is the largest prime divisor of $\binom{36}{18}$. Since 31 is a divisor of $\binom{34}{17}$ and $\binom{32}{16}$ but not of $\binom{2b}{b}$, $1 \leq b \leq 15$, we see that b must be 16 or 17 in order that equation (1.12) hold in the case $a = 18$. If $b = 16$ we find that 17 divides $\binom{32}{16}$ but not $\binom{36}{18}$, whereas if $b = 17$, $\binom{34}{17}$ is divisible by 3^3 but $\binom{36}{18}$ is not. Hence $b \neq 16, 17$, and we conclude that (1.12) is not solvable for b and c if $a = 18$.

In this manner we are able to demonstrate the unsolvability of (1.12) for $a = 1, 2, \ldots, 47$.

Essentially the same type of argument used in the proof of Theorem 1.1 will be sufficient to establish

Theorem 1.2.

The equation

$$(1.13) \qquad \frac{\binom{2a}{a}}{a+1} = \frac{\binom{2b}{b}}{b+1} \cdot \frac{\binom{2c}{c}}{c+1}$$

has no solution in positive integers a, b, and c, provided $a, b, c \neq 1$.

Proof:

In what follows we use the notation $p \,/\, a$, $p \not/\, a$ to read, respectively, "p divides a", "p does not divide a". Losing no generality in assuming $a > b \geq c$, put $a = b+x$, $x > 0$.

If $x \geq b$ then $a \geq 2b$ and the interval $(\frac{9}{8}(\frac{16}{9})a, \frac{16}{9}a)$ is contained in the interval $(2a, a+1)$. By the result of R. Breusch [2], mentioned earlier in connection with the proof of Theorem 1.1, the interval $(2a, \frac{16}{9}a)$ contains a prime p such that $2a > p > a+1 > 2b$, provided $a \geq 27$. Thus $p \,/\, \frac{\binom{2a}{a}}{a+1}$ but $p \not/\, \frac{\binom{2b}{b}}{b+1} \cdot \frac{\binom{2c}{c}}{c+1}$.

Now consider x in the range $\frac{b}{8} < x < b$. Since $\frac{9}{8} b < a < 2b$ and $a+1 \leq 2b$, the interval $(2a, a+1)$ contains the interval $(\frac{9}{8}(2b), 2b)$. Again by [2], there exists a prime p in the range $\frac{9}{4} b > p > 2b$ provided $b \geq 24$. Hence p divides the left-hand side of (1.13) but not the right-hand side.

Next, suppose $0 < x < \frac{b}{8}$. We have

$$\frac{\binom{2a}{a}}{\binom{2b}{b}} \cdot \frac{b+1}{a+1} = \frac{\binom{2b+2x}{b+x}}{\binom{2b}{b}} \cdot \frac{b+1}{b+x+1}$$

$$= 2^x \; \frac{(2b+1)(2b+3)\ \ldots\ (2b+2x-1)}{(b+2)(b+3)\ \ldots\ (b+x+1)}$$

Lemma 1.4 implies that, for $x > 33$, there exists some prime $q > 2x$ and some integer i in the range $2 \leq i \leq x+1$ such that

$$b+i \equiv 0 \pmod{q} .$$

For this prime q then

$$2b + 2j - 1 \not\equiv 0 \pmod{q} , \quad j = 1, 2, \ldots, x$$

and $(2b+1)(2b+3) \ldots (2b+2x-1) \not\equiv 0 \pmod{q}$. Consequently, the quantity

$$R_x = 2^x \frac{(2b+1)(2b+3) \ldots (2b+2x-1)}{(b+2)(b+3) \ldots (b+x+1)}$$

cannot be an integer for $33 < x < \frac{b}{8}$. Hence

$$\frac{\binom{2a}{a}}{a+1} \not\equiv 0 \left(\mathrm{mod}\ \frac{\binom{2b}{b}}{b+1}\right)$$

in this case.

Since $4^x > R_x = 2^x \left(\frac{2b+5}{b+2}\right)\left(\frac{2b+7}{b+3}\right) \ldots \left(\frac{2b+2x-1}{b+x-1}\right)\left(\frac{2b+1}{b+x}\right)\left(\frac{2b+3}{b+x+1}\right)$ we have

$$(1.14) \qquad 4^x > R_x \geq 4^x \left(\frac{2b+1}{2b+2x}\right)\left(\frac{2b+3}{2b+2x+2}\right)$$

provided $x \geq 2$.

Thus, if $b > 24$ it follows that R_x satisfies the inequality

$$4^x > R_x > 4^x \frac{(49)(51)}{(48+2x)(50+2x)} , \quad x \geq 2 .$$

Substituting the values $x = 2, 3, 4, 5$ in the above expression gives

$$(1.15)\quad \begin{aligned} 16 &> R_2 > 14.23 \\ 64 &> R_3 > 52.88 \\ 256 &> R_4 > 196.96 \\ 1024 &> R_5 > 735.3 . \end{aligned}$$

If $x = 1$ and $b > 24$, we have

$$(1.16)\quad 4 > R_1 = 4\left(\frac{2b+1}{2b+2}\right) > 3.92 .$$

The following numerical values of $\binom{2c}{c}$ for $4 \leq c \leq 8$:

$$\frac{\binom{8}{4}}{5} = 14 \qquad \frac{\binom{12}{6}}{7} = 132 \qquad \frac{\binom{16}{8}}{9} = 1,430 ,$$

$$\frac{\binom{10}{5}}{6} = 42 \qquad \frac{\binom{14}{7}}{8} = 429$$

and the set of inequalities (1.15) and (1.16) show that $R_x \neq \frac{\binom{2c}{c}}{c+1}$ for $1 \leq x \leq 5$ and $b > 24$.

To deal with the case $5 < x \leq 33$, $x < \frac{b}{8}$, we first note that:

If one of the numbers $b+2, b+3, \ldots, b+x+1$ is of the form αp, where $\alpha = 1, 2, 3$ or 4 and p is a prime > 3, then

$$p \nmid (2b+1)(2b+3) \ldots (2b+2x-1) ,$$

provided $b > 24$.

The proof of this statement follows trivially from elementary considerations. An examination of the prime factors of the numbers under 170 readily verifies the existence of a number of the form p, $2p$, $3p$, or $4p$ in the sequence $b+2, b+3, \ldots, b+x+1$ for $b \leq 150$ and $\frac{b}{8} > x > 5$. Hence, for this range of b and x, there exists a prime number $p > 3$ which divides the denominator but not the numerator of the expression for R_x. Since b must be greater than 150 in order that R_x be an integer for $\frac{b}{8} > x > 5$, expression (1.14) becomes

$$(1.17) \qquad 4^x > R_x > 4^x \frac{(301)(303)}{(300+2x)(302+2x)} \quad .$$

From this inequality the following bounds for R_6, R_7 and R_8 are obtained:

$$4096 > R_6 > 3813.58$$
$$16{,}384 > R_7 > 15{,}059.56$$
$$65{,}536 > R_8 > 59{,}480.53 \quad .$$

Now, the values:

$$\frac{\binom{16}{8}}{9} = 1{,}430 \qquad \frac{\binom{20}{10}}{11} = 16{,}796 \qquad \frac{\binom{24}{12}}{13} = 208{,}012 \; ,$$

$$\frac{\binom{18}{9}}{10} = 4{,}862 \qquad \frac{\binom{22}{11}}{12} = 58{,}786$$

imply that $R_x \neq \frac{\binom{2c}{c}}{c+1}$ for $6 \leq x \leq 8$.

The relations $R_x = 2\,\frac{(2b+2x-1)}{(b+x+1)}\,R_{x-1}$, $b > 8x$, and

$\frac{\binom{2x+6}{x+3}}{x+4} = 2\,\frac{(2x+5)}{(x+4)}\,\frac{\binom{2x+4}{x+2}}{(x+3)}$, and the inequality $R_8 > \frac{\binom{22}{11}}{12}$ imply

that

$$(1.18) \qquad R_x > \frac{\binom{2x+6}{x+3}}{(x+4)} \quad \text{for} \quad x \geq 8 .$$

Also, we saw in the proof of Theorem 1.1 that

$$\binom{2x}{x} > \frac{4^x}{2\sqrt{x}} \quad \text{for} \quad x > 1 ,$$

hence

$$(1.19) \qquad \frac{\binom{2x}{x}}{x+1} > \frac{4^x}{2\sqrt{x}\,(x+1)} , \quad x > 1$$

and

$$\frac{\binom{2x+8}{x+4}}{x+5} \geq 4^x \quad \text{provided} \quad x \leq 20.$$

Direct computation reveals that $\frac{\binom{2x+8}{x+4}}{x+5} > 4^x$ for $x = 21, 22$; that is,

$$\frac{\binom{50}{25}}{26} = 4{,}861{,}946{,}401{,}452 \quad > 4^{21} = 4{,}398{,}046{,}511{,}104$$

$$\frac{\binom{52}{26}}{27} = 18{,}367{,}353{,}072{,}152 \quad > 4^{22} = 17{,}592{,}186{,}044{,}416 \quad .$$

Thus

$$(1.20) \qquad \frac{\binom{2x+8}{x+4}}{x+5} \geq 4^x \quad \text{for} \quad 1 < x \leq 22 .$$

From inequalities (1.17), (1.18), and (1.20) we find

$$\frac{\binom{2x+8}{x+4}}{x+5} > R_x > \frac{\binom{2x+6}{x+3}}{x+4} \quad \text{for} \quad 8 \leq x \leq 22.$$

Upon examination of the tables of K. Appel and J. Rosser [1], and D. N. Lehmer [14], it is found that, apart from the following exceptions, the maximum gap between any two consecutive primes under 4738 is 22:

$$(1.21) \quad (p_n, p_{n+1}) = (1327,1361);\ (1669,1693);\ (2179,2203);\ (2477,2503);\ (2971,2999);\ (3137,3163);\ (3271,3299);\ (4177,4201);\ (4297,4327);\ (4523,4547).$$

Occurring in these intervals (p_n, p_{n+1}) are numbers of the form $2p$ or $3p$, where p is a prime > 3. That is, the intervals with end points shown in (1.21) contain, respectively, the numbers

$$1346 = 2\cdot 673;\ 1689 = 3\cdot 563;\ 2186 = 2\cdot 1093;\ 2481 = 3\cdot 827;\ 2991 = 3\cdot 997;$$
$$3147 = 3\cdot 1049;\ 3279 = 3\cdot 1093;\ 4197 = 3\cdot 1399;\ 4317 = 3\cdot 1439;\ 4533 = 3\cdot 1511.$$

From the above we deduce that for $\frac{b}{8} > x > 22$, the sequence $(b+2), (b+3), \ldots, (b+x+1)$ contains a number of the form αp, $\alpha = 1, 2$ or 3, provided $b+x+1 \leq 4738$. If R_x is to be an integer for $\frac{b}{8} > x > 22$ then we must have $b > 4211$.

Inequality (1.14) with $b > 4211$ becomes

$$4^x > R_x > 4^x \frac{(8423)(8425)}{(8422+2x)(8424+2x)} .$$

For $x = 23$ it follows that

$$70{,}368{,}744{,}177{,}664 > R_{23} > 69{,}622{,}919{,}931{,}873.$$

Since $R_{23} > \frac{\binom{54}{27}}{28} = 69{,}533{,}550{,}916{,}004$, it can be shown by induction on x that

$$(1.22)\qquad R_x > \frac{\binom{2x+8}{x+4}}{x+5} \quad \text{for} \quad x \geq 23 .$$

Furthermore, from inequality (1.19), it follows that

$$(1.23)\qquad \frac{\binom{2x+10}{x+5}}{x+6} > 4^x \quad \text{for} \quad x \leq 59 .$$

Combining (1.22) and (1.23) gives

$$\frac{\binom{2x+10}{x+5}}{x+6} > R_x > \frac{\binom{2x+8}{x+4}}{x+5}$$

provided $23 \leq x \leq 59$.

We note, in summarizing the above results, that the equation

$$(1.24)\qquad \frac{\binom{2a}{a}}{a+1} = \frac{\binom{2b}{b}}{b+1} \cdot \frac{\binom{2c}{c}}{c+1}$$

has no solution in positive integers $a > b \geq c$ if

(i) $b \geq 24$ with $2b > a \geq \frac{9}{8} b$,

(ii) $a \geq 27$ with $a \geq 2b$

and

(iii) $b \geq 24$ with $\frac{9}{8} b > a$. To complete the proof of Theorem 1.2 it will be sufficient to establish the unsolvability of (1.24) for $2a < 96$. The following example illustrates the manner in which this is accomplished.

Let $a = 14$. A reference to Table [II] of the Appendix, which gives the prime factorization of the numbers $\frac{\binom{2a}{a}}{a+1}$ for $1 \leq a \leq 47$, shows that 23 is the largest prime divisor of $\frac{\binom{28}{14}}{15}$. In order that 23 divide $\frac{\binom{2b}{b}}{b+1} \cdot \frac{\binom{2c}{c}}{c+1}$, b must be 12 or 13. For $b = 13$ we have

$5^2 \,/\, \frac{\binom{26}{13}}{14}$, $5^2 \not/\, \frac{\binom{28}{14}}{15}$, whereas $b = 12$ implies $7 \,/\, \frac{\binom{24}{12}}{13}$, $7 \not/\, \frac{\binom{28}{14}}{15}$.

Hence, equation (1.24) has no solution for $a = 14$.

Using the above scheme the unsolvability of (1.24) is established for $a = 1, 2, 3, \ldots, 47$.

CHAPTER II

Related to the general topic of prime-representing functions is the following problem mentioned by P. Erdös in [6] :

Show that for all sufficiently large n not all the integers

$$(2.1) \qquad n-2^k , \quad 1 \leq k < \frac{\log n}{\log 2}$$

can be prime.

He states: "For $n = 105$ all the integers (2.1) are prime, but it is easy to see from a study of the prime tables that in the interval $105 < n \leq 3\cdot5^2\cdot11\cdot13\cdot19 = 203,775$ there is no other such integer."

Our aim, in this chapter, is to extend the above result of Erdös by establishing the following theorem.

Theorem 2.1.

For the integer n in the range

$$105 < n \leq 10^9 ,$$

not all the integers

$$n-2^k , \quad 1 \leq k < \frac{\log n}{\log 2}$$

can be prime.

We call n an <u>exceptional integer</u> if all the numbers (2.1) are prime; thus, the numbers 7, 15, 45, and 105 qualify as exceptional

integers. To establish Theorem 2.1, we make use of the following two lemmas:

Lemma 2.1.

Let p denote a prime for which 2 is a primitive root and suppose that p does not divide n, where n is an exceptional integer. Then, if r is the integer in the range $1 \leq r \leq p-1$ for which

$$n \equiv 2^r \pmod{p},$$

we must have $n \leq 2^r + p$.

Proof:

Since $n-2^r \equiv 0 \pmod{p}$, the quantity $n-2^r$ is composite for $n > 2^r + p$; contradicting the assumption that n is an exceptional integer.

Lemma 2.2.

If 2 is a primitive root of the prime p and n is an exceptional integer, at least one of the following conditions must hold:

(i) p / n

(ii) $n \leq 2^{p-1} + p$.

Proof:

If condition (i) does not hold then there exists an integer r in the range $1 \leq r \leq p-1$ for which $n \equiv 2^r \pmod{p}$. Condition (ii) follows from the inequality $n \leq 2^r + p$ supplied by Lemma 2.1.

Now suppose that $n > 2^{p-1} + p$. If p does not divide n there exists some integer r in $1 \leq r \leq p-1$ for which $n \equiv 2^r \pmod{p}$,

implying that $n-2^r$ is composite. Hence, p must be a divisor of n if $n > 2^{p-1} + p$.

In what follows, n denotes the fifth exceptional integer, provided this number exists, in the sequence of exceptional integers

$$7, 15, 45, 105, \ldots .$$

Proof of Theorem 2.1:

To establish the theorem we prove first that the primes 3, 5, 11, 13, 19, 29, and 37 are divisors of n.

Since $n > 105$, it follows from Lemma 2.2 that both 3 and 5 divide n; on the other hand, 2 is obviously not a divisor of n. Thus,

$$n \equiv 15 \pmod{30}. \tag{2.2}$$

We use the notation $P_p(2)$ to denote the ordered set of numbers $\{\alpha_1, \alpha_2, \ldots, \alpha_r\}$ where $2^i \equiv \alpha_i \pmod p$ and r is the smallest positive integer for which $\alpha_r = 1$; for example,

$$P_{11}(2) = \{2, 4, 8, 5, 10, 9, 7, 3, 6, 1\} .$$

In order to establish 11 as a divisor of n, it suffices to show that none of the elements of $P_{11}(2)$ can be residues of n modulo 11. From Lemma 2.1,

$$n \not\equiv 2, 4, 8, 5, 10, 9 \pmod{11} .$$

Furthermore, the condition that

$$n \equiv 7 \pmod{11} \tag{2.3}$$

implies $105 < n \leq 139$. To satisfy congruence (2.2), we let $n = 30a + 15$, where a is a positive integer. Then by congruence (2.3),

$$30a + 15 \equiv 7 \pmod{11}$$

and

$$a \equiv 10 \pmod{11} .$$

Setting $a = 11b + 10$, we obtain $n = 30(11b + 10) + 15$, or

$$n \equiv 315 \pmod{330} .$$

This congruence is incompatible with the restriction $105 < n \leq 139$; hence congruence (2.3) cannot hold.

If

(2.4) $$n \equiv 3 \pmod{11} ,$$

we must have $105 < n \leq 267$. Combining congruences (2.2) and (2.4) yields

$$n \equiv 135 \pmod{330}.$$

The only possibility for n in the range $(105, 267]$ is 135, but $7 \nmid (135-2)$. It follows that $n \not\equiv 3 \pmod{11}$.

Consider the case

(2.5) $$n \equiv 6 \pmod{11} .$$

If n satisfies congruences (2.2) and (2.5), then

$$n \equiv 105 \pmod{330} .$$

By Lemma 2.1 and congruence (2.5), $105 < n \leq 523$. Thus, the only possible value of n in this case is 435. Since $7 \nmid (435-2^3)$, we see that (2.5) cannot hold.

For

(2.6) $n \equiv 1 \pmod{11}$,

we have $105 < n \leq 1035$. A combination of congruences (2.2) and (2.6) gives

$$n \equiv 45 \pmod{330} .$$

From this we obtain three possible values for n in the range $(105, 1035]$, namely: 375, 705 and 1035. Now, $7 \mid (375-2^2)$, $17 \mid (705-2^3)$, and $17 \mid (1035-2^5)$; hence $n \not\equiv 1 \pmod{11}$.

The foregoing implies that

(2.7) $n \equiv 0 \pmod{11}$.

The method used above serves also to establish the primes 13 and 19 as divisors of n. First, we combine the congruences (2.2) and (2.7) to obtain

(2.8) $n \equiv 165 \pmod{330}$.

Since $n \geq 165$ and $P_{13}(2) = \{2, 4, 8, 3, 6, 12, 11, 9, 5, 10, 7, 1\}$, we have, by Lemma 2.1,

$$n \not\equiv 2, 4, 8, 3, 6, 12, 11 \pmod{13}.$$

Table 1, below, shows the elimination of the remaining numbers of $P_{13}(2)$ as residues of n modulo 13.

TABLE 1

Residue of n (mod 13)	Residue of n (mod 4,290)	Upper Bound on n from Lemma 2.1	Possible Value(s) of n	Elimination of the possible values of n
9	165	269	165	$7/(165-2^2)$
5	2475	525	-	-
10	2805	1037	-	-
7	3465	2061	-	-
1	495	4109	495	$17/(495-2)$

To illustrate the manner in which the table is constructed, let us suppose

$$n \equiv 9 \pmod{13} .$$

This congruence, when combined with (2.8) yields

$$(2.9) \qquad n \equiv 165 \pmod{4{,}290} .$$

From Lemma 2.1, $n \equiv 9 \pmod{13}$ implies $n \leq 269$; hence, the only possible value of n satisfying (2.9) is the number 165. Since $7/(165-2^2)$, it follows that $n \not\equiv 9 \pmod{13}$. Using this procedure we obtain the remaining entries of the table.

As a result of the elimination of the numbers 1, 2, 3, ..., 12 as possible residues of n modulo 13,

$$(2.10) \qquad n \equiv 0 \pmod{13} .$$

To satisfy congruences (2.8) and (2.10), we must have

(2.11) $n \equiv 2145 \pmod{4290}$.

Now $P_{19}(2) = \{2, 4, 8, 16, 13, 7, 14, 9, 18, 17, 15, 11, 3, 6, 12, 5, 10, 1\}$, hence $n \not\equiv 2, 4, 8, 16, 13, 7, 14, 9, 18, 17, 15 \pmod{19}$ by Lemma 2.1. Elimination of the remaining numbers of $P_{19}(2)$ as residues of $n \pmod{19}$ are shown in the following table:

TABLE 2

Residue of n (mod 19)	Residue of n (mod 81,510)	Upper Bound on n from Lemma 2.1	Possible Value(s) of n	Elimination of possible values of n
11	49,335	4,115	-	-
3	57,915	8,211	-	-
6	75,075	16,403	-	-
12	27,885	32,787	27,885	$7/(27,885-2^2)$
5	15,015	65,555	15,015	$17/(15,015-2^2)$
10	70,785	131,091	70,785	$7/(70,785-2^3)$
1	19,305	262,163	19,305	$23/(19,305-2^3)$
			100,815	$7/(100,815-2^3)$
			182,325	$23/(182,325-2^2)$

Thus 19 is a divisor of n.

A technique somewhat different from the above must be employed when large numbers of possible values of n are to be investigated. To illustrate, let us suppose that the condition on n is

$n \equiv c \pmod{b}$,

where there are N possible values of n to be investigated, namely:

(2.12) $t_1 = c,\ t_2 = c+b,\ t_3 = c+2b,\ \ldots,\ t_N = c+(N-1)b$.

If p is a prime for which $p \nmid b$ then the arithmetic progression (2.12), when reduced modulo p, is periodic with period p ; that is

(2.13) $t_i \equiv t_{i+wp}$, $i = 1, 2, 3, \ldots,$ $w = 0, 1, 2, 3, \ldots$.

For $P_p(2) = \{\alpha_1, \alpha_2, \alpha_3, \ldots, \alpha_r\}$, the existence of an element α_i of $P_p(2)$ for which $t_j \equiv \alpha_i \pmod p$ implies that p divides $t_j - 2^i$. Accordingly, the number $t_j - 2^i$ is composite provided $2^i + p < t_j$; in fact, from (2.13) we have $t_s - 2^i$ composite for $s \equiv j \pmod p$ and $2^i + p < t_s$.

A sieve process, using a sequence of primes $\{p_i\}$ for which $p_i \nmid b$, $i = 1, 2, 3, \ldots$, can be set up to eliminate those numbers t_i from (2.12) which are not exceptional integers. Initially, the set S to be sieved has the elements $1, 2, 3, \ldots, N$, where $j \in S$ implies that t_j may be an exceptional integer. Let us define the set $A(p)$ as follows: for $j \in S$, $j \in A(p)$ if and only if $p/(t_j - 2^i)$ and $t_j - 2^i > p$ for some integer $i > 0$. To set up the sieve process we first choose a prime $p \in \{p_i\}$ and compute the numbers $t_1, t_2, \ldots, t_d$ modulo p, where $d = \min(p, N)$. Now for $1 \leq j \leq d$, the existence of an element α_i of $P_p(2)$ for which

$$t_j \equiv \alpha_i \pmod p$$

implies that $s \in A(p)$ provided the following conditions are satisfied:

(i) $s \in S$,

(ii) $s \equiv j \pmod p$,

and

(iii) $t_s > 2^i + p$.

Thus, we form the set $A(p)$ and eliminate from S those elements which are common to both $A(p)$ and S. To complete the process, $A(p)$ is formed for each prime p of the sequence $\{p_i\}$, or, until the set S is empty. We illustrate the above procedure by means of the following numerical example: Congruence (2.11) and the fact that 19 divides n implies

$$(2.14) \qquad n \equiv 40{,}755 \pmod{81{,}510} .$$

Suppose that $n \equiv 20 \pmod{29}$. Then, from the above congruence,

$$n \equiv 1{,}263{,}405 \pmod{2{,}363{,}790}.$$

By Lemma 2.1, we have $n \leq 16{,}777{,}245$, so that there are seven possible values of n to be checked. For the first step in the sieve process, we choose to work with the prime 7. Since

$$1{,}263{,}405 \equiv 3 \pmod 7$$

and

$$2{,}363{,}790 \equiv 2 \pmod 7 ,$$

our sequence of seven numbers reduces, modulo 7, to

$$\{3, 5, 0, 2, 4, 6, 1\} .$$

Now, $p_7(2) = \{2, 4, 1\}$. Hence $7/(t_4-2)$, $7/(t_5-2^2)$, and $7/(t_7-2^3)$, giving $A(7) = (4,5,7)$. Working next with the prime 17, we find

$$1{,}263{,}405 \equiv 16 \pmod{17}$$

$$2{,}363{,}790 \equiv 8 \pmod{17} .$$

The sequence $\{t_1, t_2, t_3, \ldots, t_7\}$ becomes

$$(2.15) \qquad \{16, 7, 15, 6, 14, 5, 13\}$$

modulo 17. Comparing the elements of $P_{17}(2) = \{2, 4, 8, 16, 15, 13, 9, 1\}$ with the numbers (2.15) yields $A(17) = (1,3)$. Choosing 23 as the next prime for the sieve process, we have

$$1{,}263{,}405 \equiv 15 \pmod{23}$$

and

$$2{,}363{,}790 \equiv 11 \pmod{23} ,$$

with the sequence

$$\{15, 3, 14, 2, 13, 1, 12\} .$$

Furthermore, $P_{23}(2) = \{2, 4, 8, 16, 9, 18, 13, 3, 6, 12, 1\}$, so that $A(23) = (2,6)$. Since $A(7) \cup A(17) \cup A(23) = (1, 2, 3, 4, 5, 6, 7)$, we conclude that $n \not\equiv 20 \pmod{29}$.

We now proceed to show that 29 is a divisor of n , using the above sieve process only when large numbers of possible values of n are to be investigated. First, $P_{29}(2) = \{2, 4, 8, 16, 3, 6, 12, 24, 19, 9, 18, 7, 14, 28, 27, 25, 21, 13, 26, 23, 17, 5, 10, 20, 11, 22, 15, 1\}$. From congruence (2.14) and Lemma 2.1, it follows immediately that $n \not\equiv 2, 4, 8, 16, 3, 6, 12, 24, 19, 9, 18, 7, 14, 28, 27 \pmod{29}$. Table 3, below, illustrates the elimination of the numbers 25, 21, 13, 26, 23, 17, 5, 10 as residues of n modulo 29.

TABLE 3

Residue of n (mod 29)	Residue of n (mod 2,363,790)	Upper Bound on n from Lemma 2.1	Possible Value(s) of n	Elimination of possible values of n
25	692,835	65,565	-	-
21	203,775	131,101	-	-
13	1,589,445	262,173	-	-
26	1,996,395	524,317	-	-
23	448,505	1,048,605	448,505	$7/(448,505-2^2)$
17	2,078,505	2,097,181	2,078,505	$7/(2,078,505-2)$
5	611,325	4,194,333	611,325	$7/(611,325-2^3)$
			2,975,115	$17/(2,975,115-2^6)$
10	40,755	8,388,637	40,755	$7/(40,755-2^3)$
			2,404,545	$37/(2,404,545-2^{22})$
			4,768,335	$31/(4,768,335-2^3)$
			7,132,125	$17/(7,132,125-2^5)$.

In the numerical example appearing earlier it was shown that $n \not\equiv 20 \pmod{29}$; thus, only the elements 11, 22, 15 and 1 of $T_{29}(2)$ remain as possible residues of n modulo 29. If we consider the case $n \equiv 11 \pmod{29}$, we have, from congruence (2.14),

$$n \equiv 1,344,915 \pmod{2,363,790} .$$

Hence, there are 14 possible values for n which satisfy both the above congruence and the inequality $n \leq 33,554,461$ given by Lemma 2.1. In the notation of expression (2.12) we have $c = 1,344,915$, $b = 2,363,790$, and $N = 14$. These results, as well as the corresponding results for the cases $n \equiv 22$, $n \equiv 15$, and $n \equiv 1 \pmod{29}$, are illustrated in Table 4 below.

TABLE 4

	Residue of n (mod 29)	Residue, c, of n (mod b = 2,363,790)	Upper Bound on n from Lemma 2.1	Number, N, of possible values of n	Elimination of possible values of n
(A)	11	1,344,915	33,554,461	14	See Table [III] (A)
(B)	22	1,507,935	67,108,893	28	See Table [III] (B)
(C)	15	1,833,975	134,217,757	57	See Table [III] (C)
(D)	1	122,265	268,435,485	114	See Table [III] (D)

In order to show that the numbers 11, 22, 15, and 1 cannot be residues of n modulo 29, we use the sieve process to eliminate, in each case, the N numbers

$$c,\ c+b,\ c+2b,\ \ldots,\ c+(N-1)b$$

as exceptional integers. Table [III] of the Appendix contains the results obtained by applying the sieve process to each of the four cases in Table 4. As an illustration let us refer to part (A) of Table [III]. Here we propose to examine the 14 numbers:

(2.16) $\quad c,\ c+b,\ c+2b,\ \ldots,\ c+13b,$

where $c = 1,344,915$ and $b = 2,363,790$, eliminating those numbers which are not exceptional integers. To apply the process we first choose the prime 7 and compute, modulo 7, the sequence $\{c, c+b, \ldots, c+db\}$, where $d = \min\ (p-1, N-1)$. Since $c \equiv 5,\ b \equiv 2 \pmod 7$ the sequence is $\{5, 0, 2, 4, 6, 1, 3\}$. If we compare the elements of this sequence with the elements of $P_7(2) = \{2, 4, 1\}$ we find:

(i) $c+ib \equiv 2 \pmod 7$ if $i \equiv 2 \pmod 7$,

(ii) $c+ib \equiv 4 \pmod 7$ if $i \equiv 3 \pmod 7$,

and

(iii) $c+ib \equiv 1 \pmod 7$ if $i \equiv 5 \pmod 7$.

Hence $c+ib$, in this case, is not an exceptional integer if $i \equiv 2, 3,$ or $5 \pmod 7$. By the definition of the set $A(p)$ then, we must have $A(7) = (3, 4, 6, 10, 11, 13)$. Repeating the above procedure for the primes 17, 23 and 37, we obtain $A(17) = (2, 5, 7, 8, 14)$, $A(23) = (1, 9)$, and $A(37) = (12)$. As a result, each of the numbers in (2.16) is eliminated as an exceptional integer and we conclude that $n \not\equiv 11 \pmod{29}$. The remaining entries of Table 4 and Table [III] of the Appendix imply $n \not\equiv 22, 15, 1 \pmod{29}$. Hence

(2.17) $n \equiv 0 \pmod{29}$.

For n to satisfy congruences (2.14) and (2.17) it must have the form

(2.18) $n \equiv 1{,}181{,}895 \pmod{2{,}363{,}790}$.

Now Lemma 2.1 implies $n \not\equiv 2, 4, 8, 16, 32, 27, 17, 34, 31, 25, 13, 26, 15, 30, 23, 9, 18, 36, 35, 33 \pmod{37}$ since $P_{37}(2) = \{2, 4, 8, 16, 32, 27, 17, 34, 31, 25, 13, 26, 15, 30, 23, 9, 18, 36, 35, 33, 29, 21, 5, 10, 20, 3, 6, 12, 24, 11, 22, 7, 14, 28, 19, 1\}$ and $n \geq 1{,}181{,}895$. Furthermore, the results of Table 5 below, indicate that the numbers 29, 21, 5, 10, 20, 3, 6, 12, and 24 cannot be residues of n modulo 37.

TABLE 5

Residue of n (mod 37)	Residue of n (mod 87,460,230)	Upper Bound on n from Lemma 2.1	Possible Value(s) of n	Elimination of possible value(s) of n
29	41,366,325	2,097,189	-	-
21	39,002,535	4,194,341	-	-
5	34,274,955	8,388,645	-	-
10	24,819,795	16,777,253	-	-
20	5,909,475	33,554,469	1	$23/(5,909,475-2^4)$
3	55,549,065	67,108,901	1	$17/(55,549,065-2^8)$
6	67,368,015	134,217,765	1	$7/(67,368,015-2^3)$
12	3,545,685	268,435,493	3,545,685	$59/(3,545,685-2^{10})$
			91,005,915	$17/(91,005,915-2)$
			178,466,145	$7/(178,466,145-2^2)$
			265,926,375	$7/(265,926,375-2^3)$
24	50,821,485	536,870,949	50,821,485	$7/(50,821,485-2^3)$
			138,281,715	$17/(138,281,715-2^7)$
			225,741,945	$7/(225,741,945-2)$
			313,202,175	$41/(313,202,175-2^8)$
			400,662,405	$17/(400,662,405-2)$
			488,122,635	$23/(488,122,635-2^9)$

Each of the remaining elements of $P_{37}(2)$, when considered as a residue of n modulo 37, gives rise to several possible values of n. To determine whether these numbers are exceptional integers we apply the sieve process, the results of which are illustrated in the following table and in Table [IV] of the Appendix.

TABLE 6

	Residue of n (mod 37)	Residue, c, of n (mod b = 87,460,230)	Upper Bound on n from Lemma 2.1	Number, N, of possible values of n	Elimination of possible values of n
(A)	11	57,912,855	1,073,741,861	12	See Table [IV] (A)
(B)	22	72,095,595	2,147,483,685	24	See Table [IV] (B)
(C)	7	13,000,845	4,294,967,333	49	See Table [IV] (C)
(D)	14	69,731,805	8,589,934,629	98	See Table [IV] (D)
(E)	28	8,273,265	17,179,869,221	197	See Table [IV] (E)
(F)	19	60,276,645	34,359,738,405	393	See Table [IV] (F)
(G)	1	76,823,175	68,719,476,773	785	See Table [IV] (G)

From the above results we find that

$$n \equiv 0 \pmod{37} ,$$

which, when combined with congruence (2.18), yields

$$n \equiv 43{,}730{,}115 \pmod{87{,}460{,}230} .$$

Now in order that a given number $t > 105$ be an exceptional integer, it must satisfy the above congruence. This restriction leaves relatively few numbers under one billion which qualify as possible exceptional integers, namely: $t_1 = 43{,}730{,}115$, $t_2 = 43{,}730{,}115 + 87{,}460{,}230, \ldots$ $t_{11} = 43{,}730{,}115 + 10(87{,}460{,}230)$. But,

$$\begin{array}{lll} 7/(t_1-2) , & 7/(t_5-2^2) , & 53/(t_9-2^9) , \\ 17/(t_2-2) , & 7/(t_6-2^3) , & 43/(t_{10}-2^8) , \\ 17/(t_3-2^7) , & 23/(t_7-2^{10}) , & 59/(t_{11}-2^{25}) ; \\ 17/(t_4-2^4) , & 7/(t_8-2) , & \end{array}$$

hence, there are no exceptional integers n in the range

$$105 < n \leq 10^9 .$$

CHAPTER III

Several unsolved problems in the theory of numbers deal with the quadratic character* of special sequences of integers. Consider, for example, the sequence of Fibonacci numbers F_n defined by

$$F_n = F_{n-1} + F_{n-2} \ , \qquad F_1 = F_2 = 1 \ .$$

It has been conjectured that the only elements of the sequence $\{F_n\}$ which are squares are $F_1 = F_2 = 1^2$ and $F_{12} = 12^2$. A similar conjecture has been made concerning the Euler numbers E_n , where

$$\frac{2}{e^x+e^{-x}} = \sum_{n=0}^{\infty} E_{2n} \frac{x^{2n}}{(2n)!} \qquad (E_{2n+1} = 0) \ ,$$

namely: The number $|E_{2n}|$ is never a square for $n > 1$. In this chapter we examine three conjectures of the above form which deal with the quadratic character of the sequences $\{n! + 1\}$, $\{T_n\}$, and $\{G_n\}$, where the numbers T_n and G_n may be defined, respectively, by means of

$$e^{x+\frac{1}{2}x^2} = \sum_{n=0}^{\infty} T_n \frac{x^n}{n!}$$

and

$$e^{e^x-1} = \sum_{n=0}^{\infty} G_n \frac{x^n}{n!} \quad .$$

The well-known conjecture of H. Brocard, [3], concerning the sequence $\{n! + 1\}$, may be stated in the following form:

The only values of the natural number n for which the diophantine equation

---

* By this we mean the property of squareness or non-squareness of numbers.

$$(3.1) \qquad n! + 1 = x^2$$

is solvable are 4, 5, and 7.

Several attempts have been made to prove the unsolvability of (3.1) for $n > 7$, but relatively little success has been obtained; see, for example, [10]. Perhaps the most successful attempt made was that of M. Kraitchik, [11], who was able to show that equation (3.1) is unsolvable for $7 < n < 1020$. His scheme, outlined by D. H. Lehmer in [13], can be described as follows: Suppose that p is a prime $> n$ and

$$(3.2) \qquad n! + 1 \equiv a \pmod p \ .$$

For $k = p-n$, multiply both sides of this congruence by

$$(n+1)(n+2) \ldots (p-1) = (p-k+1)(p-k+2) \ldots (p-1)$$

$$\equiv (-1)^{k-1}(k-1)! \pmod p$$

to obtain

$$(3.3) \qquad (p-1)! + (-1)^{k-1}(k-1)! \equiv a(-1)^{k-1}(k-1)! \pmod p \ .$$

By Wilson's theorem $(p-1)! \equiv -1 \pmod p$ so that (3.3) reduces to

$$(3.4) \qquad a \equiv 1 + \frac{(-1)^k}{(k-1)!} \pmod p \ .$$

In general, the scheme consists in examining congruence (3.4) for $k = 1, 2, 3, \ldots$ until a prime $p = k+n$ is found for which $1 + \frac{(-1)^k}{(k-1)!}$ is a quadratic non-residue of p. Since the number a, defined by means of (3.2), must be a quadratic residue of p for the equation

$n! + 1 = x^2$ to be solvable, the existence of such numbers k and p corresponding to a particular value of n implies that $n! + 1$ is not a perfect square. For example: a substitution of the values 2 and 3 for k in (3.4) yields, respectively, $a \equiv 2$ and $a \equiv \frac{1}{2} \pmod{p}$. Now, primes of the form $8x \pm 3$ have 2 as a quadratic non-residue. Hence $n! + 1 = x^2$ is not solvable if $n+2$ or $n+3$ is a prime of the form $8x \pm 3$, giving an infinite number of cases in which $n! + 1$ is not a perfect square. Kraitchik includes a table in [11] which supplies for each value of n in $1 \leq n \leq 1019$, $n \neq 4, 5, 7$, the numbers a and p for which $n! + 1 \equiv a \pmod{p}$ and for which a is a quadratic non-residue of p. Thus, by means of this table, he is able to establish the unsolvability of (3.1) for $7 < n < 1020$.

We now develop a method which utilizes the central idea of Kraitchik's scheme, namely: if $n! + 1 \equiv a \pmod{p}$ and a is a quadratic non-residue of p, then $n! + 1$ is not a perfect square. This method, ideally suited to computer use, will serve to establish the following theorem.

Theorem 3.1.

If the diophantine equation

$$(3.5) \qquad n! + 1 = x^2$$

has solutions other than $(n,x) = (4,5), (5,11), (7,71)$, then $n > 10{,}000$.

Proof:

The numbers $0, \pm 1, \pm 2, \ldots, \pm (\frac{p-1}{2})$ form a complete residue system (mod p). Thus, for any odd prime p, there are precisely $\frac{p-1}{2}$

quadratic residues. In what follows R_p and N_p denote, respectively, the set of quadratic residues including 0 and non-residues of p.

For n a positive integer and p an odd prime, let

$$n! + 1 \equiv b(n,p) \pmod p .$$

If $b(n,p) \in N_p$, it follows that (3.5) is unsolvable; but, in the case $b(n,p) \in R_p$, no definite conclusion can be drawn about the quadratic character of $n! + 1$. Intuitively, one would expect that for the randomly chosen integer n, the probability that $b(n,p) \in R_p$ is approximately $\frac{1}{2}$ for large p.

Using the above criterion, a sieve process can be designed to test the solvability of (3.5) for values of $n \leq 10{,}000$. To do this we first define S_0 to be the set of integers $\{1, 2, 3, \ldots, 10{,}000\}$ and choose a sequence of primes $\{p_i\}$, where $10{,}000 < p_1 < p_2 < \ldots$. Corresponding to each element of the sequence $\{p_i\}$ we form, successively, the sets

$$T_i = \{n;\ n \in S_{i-1},\ b(n,p_i) \in N_{p_i}\}$$

and

$$S_i = S_0 - \bigcup_{j=1}^{i} T_j$$

$$= S_{i-1} - T_i$$

for $i = 1, 2, 3, \ldots$. For $n \in \bigcup_{j=1}^{i} T_j$, say $n \in T_k$, the quantity $n! + 1$ is known not to be a square by virtue of the fact that $b(n,p_k) \in N_{p_k}$. One would expect that approximately $\frac{10{,}000}{2^i}$ elements of the set S_0 would

not be ruled out at the i^{th} stage of the process and hence would be included in the set S_i. The above iterative process is stopped at the stage $i = M$, where the number M is chosen so that the expected number of elements in S_M which are not solutions of (3.5) is less than 1.

We illustrate the above scheme with the following example.

For $S_0 = \{1, 2, 3, \ldots, 10\}$, let us choose to work with the sequence of consecutive primes $\{11, 13, 17, \ldots\}$. Since $p_1 = 11$, we have

$$N_p = N_{11} = [2, 6, 7, 8, 10] .$$

Next, for $n \in S_0$, form $n! + 1$ modulo 11 :

$$\begin{array}{lll} 1! + 1 \equiv 2 & 6! + 1 \equiv 6 & \\ 2! + 1 \equiv 3 & 7! + 1 \equiv 3 & \\ 3! + 1 \equiv 7 & 8! + 1 \equiv 6 & \pmod{11} \\ 4! + 1 \equiv 3 & 9! + 1 \equiv 2 & \\ 5! + 1 \equiv 0 & 10! + 1 \equiv 0 . & \end{array}$$

Thus $T_1 = \{n; n \in S_0, b(n,11) \in N_{11}\}$

$= \{1, 3, 6, 8, 9\}$

and $S_1 = S_0 - T_1$

$= \{2, 4, 5, 7, 10\}$.

Choosing the next prime of the sequence, we obtain $p_2 = 13$ and $N_{13} = [2, 5, 6, 7, 8, 11]$. Furthermore,

$$\begin{array}{lll} 2! + 1 \equiv 3 & 7! + 1 \equiv 10 & \\ 4! + 1 \equiv 12 & 10! + 1 \equiv 7 & \pmod{13} \\ 5! + 1 \equiv 4 & & \end{array}$$

so that $T_2 = \{10\}$ and $S_2 = \{2, 4, 5, 7\}$.

Finally, for $p_3 = 17$ and $N_{17} = [3, 5, 6, 7, 10, 11, 12, 14]$, we have

$$\begin{matrix} 2! + 1 \equiv 3 & 5! + 1 \equiv 2 \\ 4! + 1 \equiv 8 & 7! + 1 \equiv 9 \end{matrix} \pmod{17} .$$

Hence $T_3 = \{2\}$ and $S_3 = \{4, 5, 7\}$. Since we know that

$$4! + 1 = 5^2$$
$$5! + 1 = 11^2$$
$$7! + 1 = 71^2 ,$$

the sieving of S_0 is complete and we conclude that the only solutions to $n! + 1 = x^2$ for $n \leq 10$ are $(n,x) = (4,5), (5,11), (7,71)$.

The sieve process, although brief and straight-forward in application in the preceding example, becomes extremely tedious to use, manually, when the number of elements of S_0 is large. Hence, in order to apply the process to the set $S_0 = \{1, 2, 3, \ldots, 10{,}000\}$, we resort to the use of electronic computing aids.

The I.B.M. 1620 electronic computer was programmed to execute the various steps in the sieve process. The programming of the computer was facilitated by the use of the 1620 Symbolic Programming System (S.P.S), a method wherein symbolic language rather than the numerical language of the machine is used. A program written in this symbolic language and intended for translation into machine language is called a <u>source</u> program. Table [V] shows the S.P.S. source program designed for testing the solvability of (3.5) for $n \leq 10{,}000$ by means of the sieve process.

In this program, a block B of consecutive blank memory locations was reserved, the $(i+1)^{st}$ position in B corresponding to the i^{th} element of the set S_0. A second block, A, of consecutive memory locations was reserved to correspond to the numbers $0,1,2,\ldots,p-1$, respectively, for any prime p of the sequence $\{p_i\}$ used in the process. Here, the sequence of consecutive primes 10007, 10009, ... was used. In the first step of the process, the numbers $m(w)$ were formed for $w = 0,1,2,\ldots,\frac{p_1-1}{2}$, where $m(w)$ denotes the least positive residue of $w^2 (\bmod p_1)$. Flags were then placed in the positions of block A corresponding to the numbers $m(w)$. Hence, the absence of a flag in the $(i+1)^{st}$ position in A implied $i \in N_{p_1}$. Now, to begin the process of sieving, the numbers $b(n,p_1)$, where

$$n! + 1 \equiv b(n,p_1)$$

and

$$0 \leq b(n,p_1) \leq p_1 - 1 \quad ,$$

were formed for $n \in S_0$. As each number $b(n,p_1)$ was formed, the position in block A corresponding to $b(n,p_1)$ was examined. If this position contained a flag, implying that $b(n,p_1) \in R_{p_1}$, a flag would then be placed in the $(b(n,p_1)+1)^{st}$ position of B. Thus the set T_1 consisted of those elements n for which the $(n+1)^{st}$ position in block B contained no flag. Following the completion of this stage of the process, the prime p_1 and the set T_1 were output by the computer.

In general, for the i^{th} stage of the sieve process $(i > 1)$, the block A is replaced by blank memory locations and a flag then placed in position $(j+1)$ of A if $j \in R_{p_i}$. For each element n of S_{i-1}, that is for each element n for which a flag is present in position $(n+1)$ of block B, the quantity $b(n,p_i)$ is formed. The absence of a flag in position $(b(n,p_i)+1)$ of A results in the removal of the flag in the $(n+1)^{st}$ position of block B and the output of the number n, where, now, $n \in T_i$.

Approximately 65 minutes of computer time were required to sieve S_0 using the sequence of 12 consecutive primes 10007, 10009,..., 10111. Each prime p_i together with the elements of the corresponding set T_i for $i = 1,2,3, \ldots, 12$ and the resulting set S_{12} are shown as output by the computer in Table [VI] of the Appendix. Since $S_{12} = \{4,5,7\}$, we may conclude that the only solutions to equation (3.5) for $n \leq 10{,}000$ are $(n,x) = (4,5), (5,11), (7,71)$.

A generalization of equation (3.5) might be of the form $n! = x^2 - y^2$ or, further, $n! = x^d - y^d$, where d is some natural number > 1. P. Erdös and R. Obláth, [8], considered the solvability of diophantine equations of the form

$$n! = x^d \pm y^d \quad , \quad (d > 2) \ ,$$

and

$$n! \pm m! = x^d \quad , \quad (n > m > 1) \ .$$

They succeeded, in particular, in showing that the equation

$$n! = x^d - y^d$$

is unsolvable if d is any natural number which is not a power of 2 or if $d = 2^\alpha$, $\alpha \geq 3$. The method of proof which they used in the previous cases did not follow through completely in the case $d = 4$, but they were able to prove that the equation $n! = x^4 - y^4$ has at most a finite number of solutions. The problem involving $n! = x^2 - y^2$, however, is comparatively trivial.

Let us now consider the following conjecture concerning the sequence $\{T_n\}$:

The number T_n, defined by means of

$$(3.6) \qquad \sum_{n=0}^{\infty} T_n \frac{x^n}{n!} = e^{x + \frac{x^2}{2}},$$

is never a square for $n > 3$.

Originally, the T_n's arose as the number of solutions of $x^2 = 1$ in S_n, the symmetric group of degree n. The equivalence of this definition with (3.6) and with

$$(3.7) \qquad T_n = T_{n-1} + (n-1)\, T_{n-2} \qquad\qquad (T_0 = T_1 = 1)$$

was established by S. Chowla, I. Herstein, and K. Moore, [4].

In the examination of the above conjecture, we will apply a slight modification of the sieve process illustrated in the proof of Theorem 3.1. Suppose that the quadratic character of T_n for $0 \leq n \leq N$ is to be investigated. We then define S_0 to be the set of integers $\{0, 1, 2, 3, \ldots, N\}$ and delete from S_0 those elements n for which there exists a prime p such that T_n is congruent to a quadratic non-residue of p. Here, it is desirable to have a fairly simple algorithm for computing $T_n \pmod p$. Now it was shown in [4] that

$$T_{n+m} \equiv T_n \pmod m \qquad\qquad m \text{ odd}.$$

Hence, for p an odd prime, the sequence $\{T_n\}$ reduced modulo p is periodic with period p; that is

$$(3.8) \qquad T_{n+mp} \equiv T_n \pmod p, \qquad\qquad m = 0, 1, 2, 3, \ldots .$$

To determine all the elements of $\{T_n\} \pmod p$, it then suffices, because of (3.8), to compute $T_n \pmod p$ for $n = 0, 1, 2, \ldots, p-1$. This is accomplished by means of (3.7).

We now set up a sieve process for S_0 by first choosing a sequence of primes $2 < p_1 < p_2 < \ldots$. Corresponding to each element p_i of this sequence we form the set V_i where

$$V_i = \{n \; ; \; n \in S_{i-1}, \; T_n \equiv b(n,p_i), \; b(n,p_i) \in N_{p_i}\} ,$$

and the set S_i where

$$S_i = S_0 - \bigcup_{j=1}^{i} V_j$$

$$= S_{i-1} - V_i \; .$$

The periodicity of the T_n's simplifies the process of forming the set V_i considerably. For, let

$$T_n \equiv b(m,p_i) \quad (\text{mod } p_i) \; , \quad 0 \leq m \leq p_i - 1 \; ,$$

then $b(m,p_i) \in N_{p_i}$ implies $n \in V_i$ for all $n \in S_{i-1}$ such that $n \equiv m \pmod{p_i}$. The sets V_i and S_i are formed for $i = 1, 2, 3, \ldots, M$ where, due to probability considerations, we choose M to be approximately $\log N/\log 2$. The final set, S_M , of the sieve process contains those numbers n in $0 \leq n \leq N$ for which T_n may be a perfect square. The details of this process can best be illustrated by means of a numerical example. Let $N = 20$ so that $S_0 = \{0, 1, 2, 3, \ldots, 20\}$. By choosing the sequence of consecutive primes $3, 5, 7, \ldots$ to use in the sieve process we find that N_{p_1} , the set of quadratic non-residues of p_1 , takes the form

$$N_3 = [2] \; .$$

Using (3.7), we have

$$T_0 \equiv 1 \;, \quad T_1 \equiv 1 \;, \quad T_2 \equiv 2 \qquad \pmod 3 \;.$$

Since T_2 is congruent to a quadratic non-residue of 3, it cannot be a perfect square. In fact, by virtue of (3.8), T_n cannot be a square if $n \equiv 2 \pmod 3$. Thus

$$V_1 = \{2, 5, 8, 11, 14, 17, 20\}$$

and

$$S_1 = \{0, 1, 3, 4, 6, 7, 9, 10, 12, 13, 15, 16, 18, 19\} \;.$$

Repeating the above procedure for $p_2 = 5$:

$$N_5 = [2,3]$$

and, from (3.7),

$$\begin{array}{lll} T_0 \equiv 1 & T_2 \equiv 2 & T_4 \equiv 0 \\ T_1 \equiv 1 & T_3 \equiv 4 & \pmod 5 . \end{array}$$

Hence,

$$V_2 = \{7, 12\} \;,$$

$$S_2 = \{0, 1, 3, 4, 6, 9, 10, 13, 15, 16, 18, 19\} \;.$$

Now $p_3 = 7$ and

$$N_7 = [3, 5, 6] \;.$$

Computing $T_n \pmod 7$ for $n = 0, 1, 2, \ldots, 6$ gives

$$\begin{array}{lll} T_0 \equiv 1 & T_3 \equiv 4 & T_6 \equiv 6 \\ T_1 \equiv 1 & T_4 \equiv 3 & \\ T_2 \equiv 2 & T_5 \equiv 5 & \pmod 7 \;. \end{array}$$

Thus,

$$V_3 = \{4, 6, 13, 18, 19\}$$

and

$$S_3 = \{0, 1, 3, 9, 10, 15, 16\} .$$

At the fourth stage of the process we find $p_4 = 11$ and

$$N_{11} = [2, 6, 7, 8, 10] .$$

Furthermore,

$$\begin{array}{lll} T_0 \equiv 1 & T_4 \equiv 10 & T_8 \equiv 5 \\ T_1 \equiv 1 & T_5 \equiv 4 & T_9 \equiv 2 \\ T_2 \equiv 2 & T_6 \equiv 10 & T_{10} \equiv 3 \\ T_3 \equiv 4 & T_7 \equiv 1 & \qquad \pmod{11} , \end{array}$$

so that

$$V_4 = \{9, 15\} ,$$

$$S_4 = \{0, 1, 3, 10, 16\} .$$

For $p_5 = 13$,

$$N_{13} = [2, 5, 6, 7, 8, 11]$$

and

$$\begin{array}{lll} T_0 \equiv 1 & T_5 \equiv 0 & T_{10} \equiv 6 \\ T_1 \equiv 1 & T_6 \equiv 11 & T_{11} \equiv 11 \\ T_2 \equiv 2 & T_7 \equiv 11 & T_{12} \equiv 12 \\ T_3 \equiv 4 & T_8 \equiv 10 & \\ T_4 \equiv 10 & T_9 \equiv 7 & \qquad \pmod{13}. \end{array}$$

Hence

$$V_5 = \{10\} ,$$

$$S_5 = \{0, 1, 3, 16\} .$$

If $p_6 = 17$, we find that

$$N_{17} = [3, 5, 6, 7, 10, 11, 12, 14]$$

and

$$\begin{array}{lll} T_0 \equiv 1 & T_6 \equiv 8 & T_{12} \equiv 4 \\ T_1 \equiv 1 & T_7 \equiv 11 & T_{13} \equiv 7 \\ T_2 \equiv 2 & T_8 \equiv 16 & T_{14} \equiv 8 \\ T_3 \equiv 4 & T_9 \equiv 2 & T_{15} \equiv 4 \\ T_4 \equiv 10 & T_{10} \equiv 10 & T_{16} \equiv 5 \\ T_5 \equiv 9 & T_{11} \equiv 13 & \end{array} \pmod{17}.$$

Thus

$$V_6 = \{16\} ,$$

$$S_6 = \{0, 1, 3\} .$$

Combining the foregoing results we find that for $0 \leq n \leq 20$, T_n is a square only if $n = 0, 1, 3$; that is,

$$T_0 = T_1 = 1^2 \;, \; T_3 = 2^2 \;.$$

A program, written in the language of S.P.S. and illustrated in Table [VII] of the Appendix, was designed to test the quadratic character of T_n for $0 \leq n \leq 10{,}000$ by means of the sieve process. This program differed from the corresponding one of Table [V] in that

the simplifications introduced by the periodicity of the T_n's were taken into account. Compilation of the program and production were accomplished with the aid of the I.B.M. 1620 electronic computer, the total production time totalling 30 minutes. During the production run, 17 primes were found sufficient to reduce the set $S_0 = \{0, 1, 2, \ldots, 10{,}000\}$ to the set $S_{17} = \{0, 1, 3\}$. Table [VIII] of the Appendix shows each prime p_i together with the corresponding set V_i, for $i = 1, 2, 3, \ldots, 17$, as output by the computer. The last portion of the table lists the elements of S_{17}.

As a consequence of the above results, we have the following theorem:

Theorem 3.2.

The number T_n is never a square for $10{,}000 \geq n > 3$.

The Bell numbers, $\{G_n\}$, constitute an additional example of a sequence of integers whose quadratic character, at least for n bounded, is easily revealed by the application of the sieve process. These numbers, usually defined by means of

$$\sum_{n=0}^{\infty} G_n \frac{x^n}{n!} = e^{e^x-1},$$

have been the subject of many enquiries and conjectures. L. Moser and M. Wyman in [16] and [16a], list references to several of the principal results concerning the G's. A thesis of H. Finlayson, University of Alberta, gives over 50 references pertaining to these numbers. In [16], a very useful algorithm for computing G_n is described. Consider the following array of numbers:

m \ n	0	1	2	3	4
0	1	1	2	5	15
1	2	3	7		
2	5	10			
3	15				

If $G_{m,n}$ denotes the number in the mth row and the nth column, then the array is determined by:

$$G_{0,0} = G_{0,1} = 1 ,$$

$$G_{m,n} = G_{m-1,n+1} + G_{m-1,n} \qquad (m \geq 1) ,$$

$$G_{0,n+1} = G_{n,0} .$$

It follows that

$$G_{0,n} = G_n$$

from the equation

$$G_{n+1} = (G+1)^n$$

established by G. Williams, [21]. Here, the polynomial $a_n G^n + a_{n-1} G^{n-1} + \ldots + a_1 G^1 + a_0 G^0$ is to be interpreted as $a_n G_n + a_{n-1} G_{n-1} + \ldots + a_1 G_1 + a_0 G_0$.

Another useful property of the G's established in [21] is the congruence relation

(3.9) $$G_{p+n} \equiv G_n + G_{n+1} \qquad (\text{mod } p) ,$$

where p denotes a prime. Thus, the sequence $\{G_n\}$ when reduced (mod p)

must be periodic. Trivially, a necessary and sufficient condition that the numbers $G_0, G_1, \ldots, G_{r_p-1} \pmod p$ constitute a complete period is that $G_{r_p+\alpha} \equiv G_\alpha \pmod p$ for each value $0,1,2, \ldots, p-1$ of α. G. Williams, [21], proved that r_p, the length of the period, must be a divisor of $\frac{p^p-1}{p-1}$.

We now use the sieve process and the above properties of the G_n's to establish:

Theorem 3.3.

The Bell number, G_n, is never a square for $1 < n \leq 10{,}000$.

Proof:

Before proceeding with the proof of the theorem let us first develop a simple algorithm for computing $G_n \pmod p$, $n = 0, 1, 2, \ldots, N$. Consider the following array of numbers:

$$\begin{array}{llll} a_{0,0} & a_{0,1} & a_{0,2} & a_{0,3} \cdots \\ a_{1,0} & a_{1,1} & a_{1,2} \cdots & \\ a_{2,0} & a_{2,1} & & \\ \vdots & & & \end{array} \tag{3.10}$$

determined by:

$$a_{0,0} = a_{0,1} = 1 ,$$

$$a_{m,n} \equiv a_{m-1,n+1} + a_{m-1,n} \pmod p \quad (m \geq 1) , \quad (0 \leq a_{m,n} \leq p-1) , \tag{3.11}$$

$$a_{0,n+1} = a_{n,0} .$$

It is clear that $a_{0,n}$ is the least non-negative residue of G_n (mod p); that is,

$$G_n \equiv a_{0,n} \pmod{p} .$$

Thus, we will use the above array to determine $G_n \pmod{p}$ for $0 \leq n \leq p-1$. Congruence (3.9) then provides a simple method for computing $G_n \pmod{p}$ for $n = p, p+1, \ldots, \min(r_p+p-1, N)$, where r_p is the period length of the sequence $\{G_n\} \pmod{p}$ and is the smallest positive integer for which

$$G_{r_p+\alpha} \equiv G_\alpha \pmod{p} , \quad \alpha = 0, 1, 2, \ldots, p-1 .$$

If $r_p+p-1 < N$, the determination of the remaining numbers $G_n \pmod{p}$ up to $n = N$ is accomplished by means of the congruence

$$(3.12) \qquad G_{n+mr_p} \equiv G_n \pmod{p} ,$$

where $0 \leq n \leq r_p-1$ and $m = 0, 1, 2, \ldots$. This algorithm, then, will be used to compute $G_n \pmod{p}$ as required by the sieve process.

A brief description of the sieve process as applied in the investigation of the quadratic character of G_n for $0 \leq n \leq N$ follows. We first define S_0 to be the sequence of integers $\{0, 1, 2, \ldots, N\}$ and choose a sequence of primes $\{p_i\}$, where $2 < p_1 < p_2 < \ldots$. Let $b(n,p)$ denote the least non-negative residue of $G_n \pmod{p}$, that is

$$G_n \equiv b(n,p) \pmod{p}.$$

Then, corresponding to each element p_i of the sequence $\{p_i\}$, we form, successively, the sets

$$V_i = \{n \,;\, n \in S_{i-1}, b(n,p_i) \in N_{p_i}\} ,$$

N_{p_i} denoting the set of quadratic non-residues of p_i , and

$$S_i = S_0 - \bigcup_{j=1}^{i} V_j$$

$$= S_{i-1} - V_i \quad .$$

In this way, the integers n in $0 \leq n \leq N$ for which G_n is not a square are removed from S_0. As a result of forming V_i and S_i for $i = 1, 2, \ldots, M$, where M is approximately $\log N/\log 2$, we obtain the sequence of sets

$$S_0 \geq S_1 \geq S_2 \geq \ldots \geq S_M \; .$$

To complete the process, the numbers G_n for $n \in S_M$ are calculated and their quadratic character examined.

As an illustration of the above process, we prove that G_n is not a square if $1 < n \leq 20$. Let $S_0 = \{0, 1, 2, \ldots, 20\}$ and $\{p_i\} = \{3,5,7,\ldots$ the sequence of consecutive primes. The first step of any stage in the sieve process consists in forming an array equivalent in form to (3.10) by means of the set of equations (3.11), $m \leq p-2$, $n \leq p-1$. Thus, for $p = p_1 = 3$, we have the array:

$$\begin{matrix} 1 & 1 & 2 \\ 2 & & \end{matrix} \quad ,$$

which yields $G_0 \equiv G_1 \equiv 1$, $G_2 \equiv 2 \pmod 3$. From congruence (3.9) with $p = 3$,

$$G_{n+3} \equiv G_n + G_{n+1} \pmod 3 \; ;$$

hence, the sequence $\{G_0, G_1, G_2, \ldots G_{12}\}$ is equivalent (mod 3) to

(3.13) $\{1, 1, 2, 2, 0, 1, 2, 1, 0, 0, 1, 0, 1\}$.

Since $G_{13+\alpha} \equiv G_\alpha \pmod 3$ for $\alpha = 0, 1, 2$ we find that r_3 , the period length of $\{G_n\} \pmod 3$, is 13. The set of quadratic non-residues of 3, N_3 , consists of the single element 2. Thus, from (3.13), $b(n,3) \in N_3$ if $n = 2, 3, 6$. Furthermore, because of (3.12), $b(n,3) \in N_3$ if $n = 15, 16, 19$. Hence $V_1 = \{2, 3, 6, 15, 16, 19\}$ and $S_1 = \{0, 1, 4, 5, 7, 8, 9, 10, 11, 12, 13, 14, 17, 18, 20\}$. When $p = p_2 = 5$, we obtain the array:

$$\begin{array}{ccccc} 1 & 1 & 2 & 0 & 0 \\ 2 & 3 & 2 & & \\ 0 & 0 & & & \\ 0 & & & & \end{array}$$

From the above array and congruence (3.9) we have

$$\{G_0, G_1, G_2, \ldots, G_{20}\} \equiv \{1,1,2,0,0,2,3,2,0,2,0,0,2,2,2,0,2,4,4,2,2\} \pmod 5$$

and we find that $r_5 > 20$.

Since $N_5 = [2,3]$,

$$V_2 = \{5, 7, 9, 12, 13, 14, 20\}$$

and

$$S_2 = \{0, 1, 4, 8, 10, 11, 17, 18\} .$$

Using the same procedure, it can be shown that:

(i) for $p_3 = 7$,

$V_3 = \{8, 10, 17\}$,

$S_3 = \{0, 1, 4, 11, 18\}$;

(ii) for $p_4 = 11$,

$$V_4 = \{11\} ,$$

$$S_4 = \{0, 1, 4, 18\} ;$$

(iii) for $p_5 = 13$,

$$V_5 = \{4, 18\} ,$$

$$S_5 = \{0, 1\} .$$

Now $G_0 = G_1 = 1^2$, hence the quadratic character of G_n for $0 \leq n \leq 20$ has been determined. As a result, we find that G_n is never a square for $1 < n \leq 20$.

The I.B.M. 1620 electronic computer was programmed to follow the above scheme in order to investigate the quadratic character of G_n for $0 \leq n \leq 10{,}000$. Table [IX] of the Appendix illustrates the S.P.S. source program used. Here, the techniques employed in the program to form the sets V_i and S_i are seen to be equivalent to those in the programs of Tables [V] and [VII]. The total time taken to sieve the set $\{0,1,2,\ldots,10{,}000\}$ using the sequence of consecutive primes $\{3,5,7,\ldots,61\}$ was 70 minutes. At each stage of the process, the machine output the quantities p_i , $r_{p_i}-1$, and the elements of the set T_i , where the number 10,000 was output for $r_{p_i}-1$ if $r_{p_i}-1 + p_i \geq 10{,}000$. Table [X] of the Appendix lists the quantities p_i, $r_{p_i}-1$, and T_i for $i = 1, 2, \ldots, 17$ and the elements of S_{17}. The result $S_{17} = \{0,1\}$ establishes Theorem 3.3.

Recently M. Wunderlich, at the University of Colorado, investigated the quadratic character of the Fibonacci numbers $\{F_n\}$. Using an I.B.M. 709

electronic computer and essentially the same sieve process as was applied in this chapter to the sequences $\{n! + 1\}$, $\{T_n\}$, and $\{G_n\}$, he found that F_n, $1 \leq n \leq 10^6$, is a square only if $n = 1, 2, 12$.

CHAPTER IV

A theorem of Fermat states that if p is a prime, and $p \nmid a$, then

$$(4.1) \qquad a^{p-1} \equiv 1 \pmod{p} .$$

Thus,

$$(4.2) \qquad 1^{p-1} + 2^{p-1} + \ldots + (p-1)^{p-1} \equiv -1 \pmod{p} ,$$

if p is a prime. The question then arises whether or not it is necessary that p be a prime in order that congruence (4.2) hold; that is, do there exist composite n for which

$$(4.3) \qquad 1^{n-1} + 2^{n-1} + \ldots + (n-1)^{n-1} \equiv -1 \pmod{n} \ ?$$

This problem is unsolved and is included in a collection of unsolved problems of arithmetic by W. Sierpiński in [20].

In 1950, G. Giuga [9], conjectured that the answer to the above question is negative. He proved that the necessary and sufficient condition for congruence (4.3) to hold with composite modulus n is

$$\frac{n}{p} \equiv 1 \pmod{p(p-1)}$$

for each prime divisor, p, of n. From this, Giuga obtained further restrictions on n which enabled him to check his conjecture by means of considerable calculations for all $n \leq 10^{1000}$.

A line of argument very similar to that employed by Giuga will be used in this chapter to obtain the following extension of his result:

Theorem 4.1.

If the congruence

$$1^{n-1} + 2^{n-1} + \dots + (n-1)^{n-1} \equiv -1 \pmod{n}$$

is to hold for the composite modulus n, then $n > 10^{5000}$.

Proof:

We use the following lemma:

Lemma 4.1.*

Let p be a prime number and m any positive integer. Then

$$1^m + 2^m + \dots + (p-1)^m \equiv \begin{cases} -1 & \text{if } (p-1) \mid m \\ 0 & \text{if } (p-1) \nmid m \end{cases} \pmod{p}.$$

Proof of Lemma 4.1:

Let g be a primitive root of p. The numbers $g, 2g, \dots, (p-1)g$ reduced $\pmod{p}$ are the numbers $1, 2, \dots, (p-1)$ in some order; hence

$$1^m + 2^m + \dots + (p-1)^m \equiv g^m + (2g)^m + \dots + ((p-1)g)^m \pmod{p}$$

and

$$(1^m + 2^m + \dots + (p-1)^m)(g^m - 1) \equiv 0 \pmod{p}.$$

If m is not a multiple of $p-1$ then by the definition of g, $g^m - 1 \not\equiv 0 \pmod{p}$. It follows that

$$1^m + 2^m + \dots + (p-1)^m \equiv 0 \pmod{p}.$$

In the case $(p-1) \mid m$ we have, from (4.1),

$$a^m \equiv 1 \pmod{p}$$

for $(p,a) = 1$. Hence

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* A proof of this lemma is given by G. H. Hardy and E. M. Wright in "An Introduction to the Theory of Numbers."

$$1^m + 2^m + \ldots + (p-1)^m \equiv -1 \pmod p.$$

Proceeding now with the proof of Theorem 4.1, we let p be a prime divisor of n and consider the congruence $1^{n-1} + 2^{n-1} + \ldots + n^{n-1} \equiv -1 \pmod n$ modulo p. Then

$$(4.4) \qquad (1^{n-1} + 2^{n-1} + \ldots + (p-1)^{n-1})\left(\frac{n}{p}\right) \equiv -1 \pmod p .$$

The relation $1^{n-1} + 2^{n-1} + \ldots + (p-1)^{n-1} \not\equiv 0 \pmod p$ implies, from Lemma 4.1, that $(p-1)/(n-1)$; that is,

$$(4.5) \qquad p \,/\, n \text{ implies } (p-1)/(n-1) .$$

Again from Lemma 4.1,

$$1^{n-1} + 2^{n-1} + \ldots + (p-1)^{n-1} \equiv -1 \pmod p .$$

A comparison of this congruence with (4.4) yields

$$(4.6) \qquad \frac{n}{p} \equiv 1 \pmod p .$$

Clearly, (4.6) is equivalent to

$$n \equiv p \pmod{p^2} ,$$

which proves that n is squarefree and thus of the form $n = p \cdot q \cdot r \cdot \ldots$, where $p, q, r, \ldots$ denote distinct primes. Furthermore, since n is squarefree and assumed composite, it has at least one odd prime divisor, say p. By (4.5), we then have $(p-1)/(n-1)$, which implies that $n-1$ is even and hence n is odd.

A congruence of the form (4.6) must hold for each prime divisor of n , so that by multiplying all of these congruences together we obtain

(4.7) $$(\frac{n}{p} - 1)(\frac{n}{q} - 1)(\frac{n}{r} - 1) \ldots \equiv 0 \pmod{n} .$$

To simplify this congruence we note that products involving two or more distinct factors of the form $\frac{n}{p}$ are divisible by n ; hence (4.7) reduces to

$$n \sum_{p/n} \frac{1}{p} \equiv 1 \pmod{n} .$$

It follows that

$$\sum_{p/n} \frac{1}{p} \equiv \frac{1}{n} \pmod{1} ,$$

and since we are assuming n composite

(4.8) $$\sum_{p/n} \frac{1}{p} \geq 1 + \frac{1}{n} .$$

Now if p is any prime divisor of n and q is a prime $> p$ such that $q \equiv 1 \pmod{p}$, then $q \not/ n$. For suppose that q / n. From (4.5), $(q-1)/(n-1)$; but, since $p/(q-1)$, it follows that $p/(n-1)$, which contradicts the assumption that p/n. Thus, the elements p_i , where $2 < p_1 < p_2 < \ldots < p_k$, occurring in the series $\sum_{p/n} \frac{1}{p}$ of (4.8) have the property that

$$p_j \not\equiv 1 \pmod{p_i}$$

for every i and j such that $1 \leq i \leq k$, $i \leq j \leq k$.

In this connection it is of interest to consider the properties of any sequence of primes $2 < p_1 < p_2 < \dots$ for which

$$p_j \not\equiv 1 \pmod{p_i}$$

for every i and j and to examine the behaviour of the counting function $A(x)$ of those sequences, where

$$A(x) = \sum_{p_i \leq x} 1 .$$

P. Erdös, [7] investigated the behaviour of $A(x)$ in the special case $p_1 = 3$, $p_2 = 5$, $p_3 = 17$, ... , where, in general, p_j is the smallest prime for which $p_j \not\equiv 1 \pmod{p_i}$, $1 \leq i < j$. He proved that

$$A(x) = (1 + o(1)) \frac{x}{\log x \ \log\log x} \tag{4.9}$$

and indicated that arguments similar to those used in obtaining (4.9) would establish the following more general result:

Let $r \geq 1$, $Q_1 > r + 1$, Q_1 prime. Take Q_{i+1} to be the smallest prime greater than Q_i so that $Q_i \not\equiv t \pmod{Q_j}$, $1 \leq j \leq i$, $1 \leq t \leq r$.

If $B_{Q_i,r}(x)$ denotes the number of Q's not exceeding x, then

$$B_{Q_1,r}(x) = (1 + o(1)) \frac{x}{\log x \ \log_2 x \dots \log_{r+1} x} , \tag{4.10}$$

where $\log_k x$ represents the k times iterated logarithm.

Now let p_1 be any prime number greater than 2 and denote by p_{i+1} the smallest prime greater than p_i so that $p_i \not\equiv 1 \pmod{p_j}$,

$1 \leq j < i$. Then, clearly, each choice of p_1 gives rise to a sequence of primes $s(p_1) = \{p_1, p_2, p_3, \ldots\}$ for which $s(p_1)$ or any subsequence of $s(p_1)$ constitutes a possible set of prime divisors of the modulus n of (4.3). Furthermore, from (4.10), the counting function of $s(p_1)$ is:

$$B_{p_{1,1}}(x) = (1 + o(1)) \frac{x}{\log x \operatorname{loglog} x} .$$

It follows that $\sum_{p \leq s(p_1)} \frac{1}{p}$ diverges and, hence, that inequality (4.8) holds for some values of n.

We now return to the proof of Theorem 4.1 and show that inequality (4.8) is false if $n \leq 10^{5000}$.

Let $s = \{p_1, p_2, \ldots, p_k\}$ be any sequence of primes for which $2 < p_1 < p_2 < \ldots < p_k \leq 4751$ and $p_j \not\equiv 1 (\operatorname{mod} p_i)$, $1 \leq i \leq k$, $1 \leq j \leq k$. It can be shown by laborious computation* that for every sequence s of primes satisfying these conditions

$$(4.11) \qquad \sum_{p \in s} \frac{1}{p} < 0.86477\,05997 .$$

Referring to the recent table of K. Appel and J. B. Rosser, [1], we find

$$\sum_{p \leq 4751} \frac{1}{p} = 2.39925\,39252 , \qquad \sum_{p \leq 16301} \frac{1}{p} = 2.51587\,73552 ,$$

$$\theta(4751) = 4665.35934 , \qquad \theta(16301) = 16177.47129 ,$$

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* The details of these computations are in the author's possession.

where $\theta(x) = \sum_{p \leq x} \log p$. Thus,

$$(4.12) \qquad \sum_{4751 < p \leq 16301} \frac{1}{p} = 0.13522\ 94003$$

and

$$(4.13) \qquad \theta(16301) - \theta(4751) = 11512.11195 .$$

Now if t denotes any sequence of primes $\{p_1, p_2, \ldots, p_k\}$ for which $2 < p_1 < p_2 < \ldots < p_k \leq 16301$ and $p_j \not\equiv 1 \pmod{p_i}$, $1 \leq i \leq k$, $1 \leq j \leq k$, then

$$\sum_{p \epsilon t} \frac{1}{p} < \sum_{\substack{p \epsilon t \\ p \leq 4751}} \frac{1}{p} + \sum_{4751 < p \leq 16301} \frac{1}{p}$$

$$< 1$$

from (4.11) and (4.12). Since $3 \prod_{4751 < p \leq 16301} p > 10^{5000}$ by (4.13), it follows that inequality (4.8) is false for all $n \leq 10^{5000}$. For, suppose that $q_1 < q_2 < \ldots < q_h$ is a set of distinct primes such that

$$q_1 \cdot q_2 \cdot \ldots \cdot q_h = n$$

and

$$\sum_{q/n} \frac{1}{q} > 1 .$$

Define k to be the largest integer for which $q_k \leq 4751$, where $k = 0$ if $q_1 > 4751$; then, from (4.11),

$$\sum_{i=1}^{k} \frac{1}{q_i} < 0.86477\ 05997 .$$

Furthermore, $\sum_{q/n} \frac{1}{q} > 1$, so that

$$\sum_{i=k+1}^{h} \frac{1}{q_i} > \sum_{4751<p\leq 16301} \frac{1}{p}$$

and $h-k > \pi(16301) - \pi(4751)$. Hence

$$\prod_{q/n} q \geq \prod_{i=k+1}^{h} q_i > 3 \prod_{4751<p\leq 16301} p > 10^{5000} .$$

It follows that inequality (4.8) must be false for all $n \leq 10^{5000}$, implying that the congruence

$$1^{n-1} + 2^{n-1} + \ldots + (n-1)^{n-1} \equiv -1 \pmod{n}$$

cannot hold if n is composite and $n \leq 10^{5000}$.

It is interesting to compare the problem considered in this chapter with the analogous problem concerning Wilson's theorem. Here, if p is a prime,

$$(p-1)! + 1 \equiv 0 \pmod{p} , \tag{4.14}$$

and it is comparatively trivial to prove that (4.14) holds if and only if p is a prime. However, in the congruence

$$1^{p-1} + 2^{p-1} + \ldots + (p-1)^{p-1} \equiv -1 \pmod{p} ,$$

derived from Fermat's theorem, the problem of determining whether or not it is necessary that the modulus be a prime is still unsolved.

Another interesting unsolved problem deals with the equation

$$(4.15) \qquad 1^n + 2^n + \ldots + (m-1)^n = m^n$$

for which P. Erdös conjectured that the only solution in integers is $1+2 = 3$. L. Moser, [17], examined the corresponding congruence

$$1^n + 2^n + \ldots + (m-1)^n \equiv m^n , \quad n > 1$$

with various moduli. He obtained restrictions on m and n which then enabled him to prove that if (4.15) has solutions with $n > 1$ then $m > 10^{1000000}$.

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APPENDIX

TABLE [I]

EXPONENT OF THE PRIME (P) IN THE PRIME FACTORIZATION OF $\binom{2a}{a}$

P / a	2	3	5	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61
1	1																	
2	1	1																
3	2	-	1															
4	1	-	1	1														
5	2	2	-	1														
6	2	1	-	1	1													
7	3	1	-	-	1	1												
8	1	2	1	-	1	1												
9	2	-	1	-	1	1	1											
10	2	-	-	-	1	1	1	1										
11	3	1	-	1	-	1	1	1										
12	2	-	-	1	-	1	1	1	1									
13	3	-	2	1	-	-	1	1	1									
14	3	3	2	-	-	-	1	1	1									
15	4	2	1	-	-	-	1	1	1	1								
16	1	2	1	-	-	-	1	1	1	1	1							
17	2	3	1	-	1	-	-	1	1	1	1							
18	2	1	2	1	1	-	-	1	1	1	1							
19	3	1	2	1	1	-	-	-	1	1	1	1						
20	2	2	1	1	1	1	-	-	1	1	1	1						
21	3	1	1	-	1	1	-	-	1	1	1	1	1					
22	3	1	1	-	-	1	-	-	1	1	1	1	1	1				
23	4	3	2	-	-	1	-	-	-	1	1	1	1	1				
24	2	2	2	-	-	1	-	-	-	1	1	1	1	1	1			
25	3	2	-	2	-	1	-	-	-	1	1	1	1	1	1			
26	3	3	-	2	-	-	1	-	-	1	1	1	1	1	1			
27	4	-	-	2	-	-	1	-	-	1	1	1	1	1	1	1		
28	3	-	1	1	1	-	1	-	-	1	1	1	1	1	1	1		
29	4	1	1	1	1	-	1	1	-	-	1	1	1	1	1	1		
30	4	-	-	1	1	-	1	1	-	-	1	1	1	1	1	1	1	

a \ p	2	3	5	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61	67	71	73	79	83	89	97	101	103	107	109	113	127	131	137
31	5	-	-	1	1	-	1	1	-	-	-	1	1	1	1	1	1	1															
32	1	2	-	2	1	-	1	1	-	-	-	1	1	1	1	1	1	1															
33	2	1	1	2	-	1	1	1	-	-	-	1	1	1	1	1	1	1															
34	2	1	1	2	-	1	-	1	-	-	-	1	1	1	1	1	1	1	1														
35	3	2	-	1	-	1	-	1	1	-	-	1	1	1	1	1	1	1	1														
36	2	-	-	1	-	1	-	1	1	-	-	1	1	1	1	1	1	1	1	1													
37	3	-	-	1	-	1	-	1	1	-	-	-	1	1	1	1	1	1	1	1	1												
38	3	1	2	1	-	1	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1												
39	4	-	2	2	1	-	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1												
40	2	-	1	2	1	-	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1	1											
41	3	4	1	2	1	-	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1											
42	3	3	1	1	1	-	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1	1										
43	4	3	2	1	1	-	1	-	1	-	-	-	-	-	1	1	1	1	1	1	1	1	1										
44	3	4	2	1	-	-	1	-	1	1	-	-	-	-	1	1	1	1	1	1	1	1	1										
45	4	2	1	1	-	-	1	-	1	1	-	-	-	-	1	1	1	1	1	1	1	1	1	1									
46	4	2	1	2	-	1	1	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1	1									
47	5	3	1	2	-	1	1	-	-	1	1	-	-	-	-	1	1	1	1	1	1	1	1	1									

TABLE [II]

EXPONENT OF THE PRIME (P) IN THE PRIME FACTORIZATION OF $\binom{2a}{a}/a+1$

P a	2	3	5	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61	67	71	73	79	83	89	97	101
1																										
2	1																									
3	-	-	1																							
4	1	-	-	1																						
5	1	1	-	1																						
6	2	1	-	-	1																					
7	-	1	-	-	1	1																				
8	1	-	1	-	1	1																				
9	1	-	-	-	1	1	1																			
10	2	-	-	-	-	1	1	1																		
11	1	-	-	1	-	1	1	1																		
12	2	-	-	1	-	-	1	1	1																	
13	2	-	2	-	-	-	1	1	1																	
14	3	2	1	-	-	-	1	1	1																	
15	-	2	1	-	-	-	1	1	1	1																
16	1	2	1	-	-	-	-	1	1	1	1															
17	1	1	1	-	1	-	-	1	1	1	1															
18	2	1	2	1	1	-	-	-	1	1	1															
19	1	1	1	1	1	-	-	-	1	1	1	1														
20	2	1	1	-	1	1	-	-	1	1	1	1														
21	2	1	1	-	-	1	-	-	1	1	1	1	1													
22	3	1	1	-	-	1	-	-	-	1	1	1	1	1												
23	1	2	2	-	-	1	-	-	-	1	1	1	1	1												

a \ p	2	3	5	7	11	13	17	19	23	29	31	37	41	43	47	53	59	61	67	71	73	79	83	89	97	101	103	107	109
24	2	2	-	-	-	1	-	-	-	1	1	1	1	1	1														
25	2	2	-	2	-	-	-	-	-	1	1	1	1	1	1														
26	3	-	-	2	-	-	1	-	-	1	1	1	1	1	1														
27	2	-	-	1	-	-	1	-	-	1	1	1	1	1	1	1													
28	3	-	1	1	1	-	1	-	-	-	1	1	1	1	1	1													
29	3	-	-	1	1	-	1	1	-	-	1	1	1	1	1	1													
30	4	-	-	1	1	-	1	1	-	-	-	1	1	1	1	1	1												
31	-	-	-	1	1	-	1	1	-	-	-	1	1	1	1	1	1	1											
32	1	1	-	2	-	-	1	1	-	-	-	1	1	1	1	1	1	1											
33	1	1	1	2	-	1	-	1	-	-	-	1	1	1	1	1	1	1											
34	2	1	-	1	-	1	-	1	-	-	-	1	1	1	1	1	1	1	1										
35	1	-	-	1	-	1	-	1	1	-	-	1	1	1	1	1	1	1	1										
36	2	-	-	1	-	1	-	1	1	-	-	-	1	1	1	1	1	1	1	1									
37	2	-	-	1	-	1	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1								
38	3	-	2	1	-	-	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1								
39	1	-	1	2	1	-	-	-	1	-	-	-	1	1	1	1	1	1	1	1	1								
40	2	-	1	2	1	-	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1							
41	2	3	1	1	1	-	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1							
42	3	3	1	1	1	-	-	-	1	-	-	-	-	-	1	1	1	1	1	1	1	1	1						
43	2	3	2	1	-	-	1	-	1	-	-	-	-	-	1	1	1	1	1	1	1	1	1						
44	3	2	1	1	-	-	1	-	1	1	-	-	-	-	1	1	1	1	1	1	1	1	1						
45	3	2	1	1	-	-	1	-	-	1	-	-	-	-	1	1	1	1	1	1	1	1	1	1					
46	4	2	1	2	-	1	1	-	-	1	-	-	-	-	-	1	1	1	1	1	1	1	1	1					
47	1	2	1	2	-	1	1	-	-	1	1	-	-	-	-	1	1	1	1	1	1	1	1	1					

TABLE [III]

A SIEVE PROCESS APPLIED TO THE

NUMBERS 1, 2, 3, ..., N.

CORRESPONDING TO THE SEQUENCE c, c+b, c+2b, ..., c+(N-1)b.

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)*
(A)N=14	7	5	2	{5,0,2,4,6,1,3}	(3,4,6,10,11,13)
	17	11	8	{11,2,10,1,9,0,8,16,7, 15,6,14,5,13}	(2,5,7,8,14)
	23	13	11	{13,1,12,0,11,22,10,21, 9,20,8,19,7,18}	(1,9)
	37	2	8	{2,10,18,26,34,5,13,21, 29,0,8,16,24,32}	(12)
(B)N=28	7	2	2	{2,4,6,1,3,5,0}	(1,2,4,8,9,11,15, 16,18,22,23,25)
	17	1	8	{1,9,0,8,16,7,15,6,14, 5,13,4,12,3,11,2,10}	(5,7,12,19,21,24, 28)
	23	1	11	{1,12,0,11,22,10,21,9, 20,8,19,7,18,6,17,5,16, 4,15,3,14,2,13}	(10,13,14,17,20)
	37	0	8	{8,16,24,32,3,11,19,27, 35,6,14,22,30,1,9,17, 25,33,4,12,20,28,36,7, 15,23,31,2}	(26,27)
	43	11	37	{11,5,42,36,30,24,18,12, 6,0,37,31,25,19,13,7,1,38, 32,26,20,14,8,2,39,33,27, 21}	(6)
	47	34	19	{34,6,25,44,16,35,7,26, 45,17,36,8,27,46,18,37, 9,28,0,19,38,10,29,1, 20,39,11,30}	(47)

* The set A(p) consists of those numbers i to be eliminated from the remaining numbers in the set 1,2,3,...,N by virtue of the fact that $c+(i-1)b \equiv 2^r \pmod p$, r in the range $1 \leq r \leq p-1$, and $c+(i-1)b > 2^r+p$.

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
(C)N=57	7	3	2	{3,5,0,2,4,6,1}	(4,5,7,11,12,14, 18,19,21,25,26, 28,32,33,35,39, 40,42,46,47,49, 53,54,56)
	17	15	8	{15,23,14,5,13,4,12,3,11, 2,10,1,9,0,8,16,7}	(1,6,10,13,15,16, 22,23,27,29,30, 44,50,52,57)
	23	1	11	{1,12,0,11,22,10,21,9, 20,8,19,7,18,6,17,5, 16,14,15,3,14,2,13}	(2,8,17,20,24,31, 36,37,41,43,45, 48)
	31	15	9	{15,24,2,11,20,29,7,16, 25,3,12,21,30,8,17,26, 4,13,22,0,9,18,27,5,14, 23,1,10,19,28,6}	(3,34)
	37	33	8	{33,4,12,20,28,36,7,15,23, 31,2,10,18,26,34,5,13,21, 29,0,8,16,24,32,3,11,19, 27,35,6,14,22,30,1,9,17, 25}	(9,38,51,55)
(D)N=114	7	3	2	{3,5,0,2,4,6,1}	(4,5,7,11,12,14,18, 19,21,25,26,28,32, 33,35,39,40,42,46, 47,49,53,54,56,60, 61,63,67,68,70,74, 75,77,81,82,84,88, 89,91,95,96,98,102, 103,105,109,110, 112)
	17	1	8	{1,9,0,8,16,7,15,6,14, 5,13,4,12,3,11,2,10}	(1,2,6,22,24,29,36, 38,41,45,50,52,55, 58,62,69,72,73,79, 80,86,87,90,92,97, 101,104,106,107, 113,114)
	23	20	11	{20,8,19,7,18,6,17,5,16, 4,15,3,14,2,13,1,12,0, 11,22,10,21,9}	(6,9,10,15,17,23, 37,48,71,94,51,78, 83,85,108)
	31	1	9	{1,10,19,28,6,15,24,2, 11,20,29,7,16,25,3,12,21, 30,8,17,26,4,13,22,0,9, 18,27,5,14,23}	(8,13,44)

Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
37	17	8	{17,25,33,4,12,20,28,36, 7,15,23,31,2,10,18,26,34, 5,13,21,29,0,8,16,24,32, 3,11,19,27,35,6,14,22,30, 1,9}	(30,31,57,76,100, 111)
41	3	17	{3,20,37,13,30,6,23,40,16, 33,9,26,2,19,36,12,29,5, 22,39,15,32,8,25,1,18,35, 11,28,4,21,38,14,31,7,24, 0,17,34,10,27}	(34,64,65,66,93)
43	16	37	{16,10,4,41,35,29,23,17, 11,5,42,36,30,24,18,12,6, 0,37,31,25,19,13,7,1,38, 32,26,20,14,8,2,39,33,27, 21,15,9,3,40,34,28,22}	(3,27,43)
47	18	19	{18,37,9,28,0,19,38,10,29, 1,20,39,11,30,2,21,40,12, 31,3,22,41,13,32,4,23,42, 14,33,5,24,43,15,34,6,25, 44,16,35,7,26,45,17,36,8, 27,46}	(20)
53	47	52	{47,46,45,44,43,42,41,40, 39,38,37,36,35,34,33,32, 31,30,29,28,27,26,25,24, 23,22,21,20,19,18,17,16, 15,14,13,12,11,10,9,8,7, 6,5,4,3,2,1,0,52,51,50, 49,48}	(99)
67	57	30	{57,20,50,13,43,6,36,66, 29,59,22,52,15,45,8,38, 1,31,61,24,54,17,47,10, 40,3,33,63,26,56,19,49, 12,42,5,35,65,28,58,21, 51,14,44,7,37,0,30,60, 23,53,16,46,9,39,2,32, 62,25,55,18,48,11,41,4, 34,64,27}	(59)

TABLE [IV]

A SIEVE PROCESS APPLIED TO THE

NUMBERS 1, 2, 3, ..., N.

CORRESPONDING TO THE SEQUENCE c, c+b, c+2b, ..., c+(N-1)b.

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
(A)N=12	7	0	4	{0,4,1,5,2,6,3}	(2,3,5,9,10,12)
	17	9	7	{9,16,6,13,3,10,0,7,14,4, 11,1}	(1,4)
	23	5	16	{5,21,14,7,0,16,9,2,18, 11,4,20}	(6,7,8,11)
(B)N=24	7	5	4	{5,2,6,3,0,4,1}	(2,6,7,9,13,14,16, 20,21,23)
	17	6	7	{6,13,3,10,0,7,14,4,11,1, 8,15,5,12,2,9,16}	(8,10,11,12,15,17, 19)
	23	2	16	{2,18,11,4,20,13,6,22,15, 8,1,17,10,3,19,12,5,21, 14,7,0,16,9}	(1,4,22,24)
	41	6	14	{6,20,34,7,21,35,8,22,36, 9,23,37,10,24,38,11,25, 39,12,26,40,13,27,0}	(5)
	43	32	36	{32,25,18,11,4,40,33,26, 19,12,5,41,34,27,20,13,6, 42,35,28,21,14,7,0}	(18)
	53	13	1	{13,14,15,16,17,18,19,20, 21,22,23,24,25,26,27,28, 29,30,31,32,33,34,35,36}	(3)
(C)N=49	7	4	4	{4,1,5,2,6,3,0}	(1,2,4,8,9,11,15, 16,18,22,23,25, 29,30,32,36,37,39, 43,44,46)
	17	10	7	{10,0,7,14,4,11,1,8,15, 5,12,2,9,16,6,13,3}	(5,7,12,13,24,26, 31,33,41,42,47,48)

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
	23	3	16	{3,19,12,5,21,14,7,0,16, 9,2,18,11,4,20,13,6,22, 15,8,1,17,10}	(3,10,14,17,20,21, 34,35,40,49)
	31	3	23	{3,26,18,10,2,25,17,9,1, 24,16,8,0,23,15,7,30, 22,14,6,29,21,13,5,28, 20,12,4,27,19,11}	(28)
	47	34	45	{34,32,30,28,26,24,22,20, 18,16,14,12,10,8,6,4,2, 0,45,43,41,39,37,35,33, 31,29,27,25,23,21,19,17, 15,13,11,9,7,5,3,1,46, 44,42,40,38,36}	(6,38)
	53	51	1	{51,52,0,1,2,3,4,5,6,7,8, 9,10,11,12,13,14,15,16, 17,18,19,20,21,22,23,24, 25,26,27,28,29,30,31,32, 33,34,35,36,37,38,39,40, 41,42,43,44,45,46}	(19,27)
	61	37	16	{37,53,8,24,40,56,11,27, 43,59,14,30,46,1,17,33, 49,4,20,36,52,7,23,39, 55,10,26,42,58,13,29,45, 0,16,32,48,3,19,35,51,6, 22,38,54,9,25,41,57,12}	(45)
(D)N=98	7	3	4	{3,0,4,1,5,2,6}	(3,4,6,10,11,13,17, 18,20,24,25,27,31, 32,34,38,39,41,45, 46,48,52,53,55,59, 60,62,66,67,69,73, 74,76,80,81,83,87, 88,90,94,95,97)
	17	15	7	{15,5,12,2,9,16,6,13,3, 10,0,7,14,4,11,1,8}	(1,5,8,14,16,21,22, 23,33,35,40,42,50, 56,57,65,72,82,84, 86,89,91,93)
	23	14	16	{14,7,0,16,9,2,18,11,4, 20,13,6,22,15,8,1,17, 10,3,19,12,5,21}	(7,9,12,15,19,28,29, 30,44,51,58,61,75, 78,85,96)

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
	31	2	23	{2,25,17,9,1,24,16,8,0,23, 15,7,30,22,14,6,29,21,13, 5,28,20,12,4,27,19,11,3, 26,18,10}	(36,63,70,98)
	41	30	14	{30,3,17,31,4,18,32,5,19, 33,6,20,34,7,21,35,8,22, 36,9,23,37,10,24,38,11, 25,39,12,26,40,13,27,0, 14,28,1,15,29,2,16}	(37,47,68)
	43	38	36	{38,31,24,17,10,3,39,32, 25,18,11,4,40,33,26,19, 12,5,41,34,27,20,13,6,42, 35,28,21,14,7,0,36,29,22, 15,8,1,37,30,23,16,9,2}	(26,43,54,64,71, 77,79)
	47	20	45	{20,18,16,14,12,10,8,6,4, 2,0,45,43,41,39,37,35,33, 31,29,27,25,23,21,19,17, 15,13,11,9,7,5,3,1,46,44, 42,40,38,36,34,32,30,28, 26,24,22}	(2,49)
	53	23	1	{23,24,25,26,27,28,29,30, 31,32,33,34,35,36,37,38, 39,40,41,42,43,44,45,46, 47,48,49,50,51,52,0,1,2, 3,4,5,6,7,8,9,10,11,12, 13,14,15,16,17,18,19,20, 21,22}	(92)
(E)N=197	7	0	4	{0,4,1,5,2,6,3}	(2,3,5,9,10,12,16, 17,19,23,24,26,30, 31,33,37,38,40,44, 45,47,51,52,54,58, 59,61,65,66,68,72, 73,75,79,80,82,86, 87,89,93,94,96,100, 101,103,107,108, 110,114,115,117, 121,122,124,128, 129,131,135,136, 138,142,143,145, 149,150,152,156, 157,159,163,164, 166,170,171,173, 177,178,180,184, 185,187,191,192, 194)

Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
17	11	7	{11,1,8,15,5,12,2,9,16,6, 13,3,10,0,7,14,4}	(4,7,8,11,20,21, 25,28,34,36,41,42, 43,53,55,60,62,70, 71,76,77,85,88,92, 102,104,105,106, 109,111,113,119, 123,126,127,130, 139,140,144,147, 153,155,160,161, 162,172,174,179, 181,189,190,195, 196)
23	4	16	{4,20,13,6,22,15,8,1,17, 10,3,19,12,5,21,14,7,0, 16,9,2,18,11}	(1,13,22,27,49,50, 57,67,90,91,95,99, 112,116,118,134, 137,141,146,151, 158,165,168,169, 182,183,188,197)
31	16	23	{16,8,0,23,15,7,30,22, 14,6,29,21,13,5,28,20, 12,4,27,19,11,3,26,18, 10,2,25,17,9,1,24}	(18,32,63,64,125, 154)
41	39	14	{39,12,26,40,13,27,0,14, 28,1,15,29,2,16,30,3, 17,31,4,18,32,5,19,33, 6,20,34,7,21,35,8,22, 36,9,23,37,10,24,38,11, 25}	(14,29,74,133,193)
43	22	36	{22,15,8,1,37,30,23,16,9, 2,38,31,24,17,10,3,39, 32,25,18,11,4,40,33,26, 19,12,5,41,34,27,20,13,6, 42,35,28,21,14,7,0,36,29}	(35,46,78,81,132, 167,175,176)
47	43	45	{43,41,39,37,35,33,31,29, 27,25,23,21,19,17,15,13, 11,9,7,5,3,1,46,44,42,40, 38,36,34,32,30,28,26,24, 22,20,18,16,14,12,10,8,6, 4,2,0,45}	(39,56,69,84,98, 186)

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
	53	18	1	{18,19,20,21,22,23,24,25, 26,27,28,29,30,31,32,33, 34,35,36,37,38,39,40,41, 42,43,44,45,46,47,48,49, 50,51,52,0,1,2,3,4,5,6, 7,8,9,10,11,12,13,14,15, 16,17}	(6,12,15,97,120, 148)
	67	38	38	{38,9,47,18,56,27,65,36,7, 45,16,54,25,63,34,5,43, 14,52,23,61,32,3,41,12, 50,21,59,30,1,39,10,48, 19,57,28,66,37,8,46,17, 55,26,64,35,6,44,15,53, 24,62,33,4,42,13,51,22, 60,31,2,40,11,49,20,58, 29,0}	(83)
(F)N=393	7	2	4	{2,6,3,0,4,1,5}	See (1) on page 85
	17	0	7	{0,7,14,4,11,1,8,15,5, 12,2,9,16,6,13,3,10}	(4,7,11,21,23,24, 25,28,30,32,38,42, 45,46,49,58,59,63, 66,72,74,79,80,81, 91,93,98,100,108, 109,114,115,123, 126,130,140,142, 143,144,147,149, 151,157,161,164, 165,168,177,178, 182,185,191,193, 198,199,200,210, 212,217,219,227, 228,233,234,242, 245,249,259,261, 262,263,266,268, 270,276,280,283, 284,287,296,297, 301,304,310,312, 317,318,319,329, 331,336,338,346, 347,352,353,361, 364,368,378,380, 381,382,385,387, 389)

Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
23	16	16	{16,9,2,18,11,4,20,13,6, 22,15,8,1,17,10,3,19, 12,5,21,14,7,0}	(2,3,9,16,18,31, 35,39,52,70,73, 77,87,94,95,101, 105,116,119,121, 128,133,150,154, 156,163,170,179, 186,192,196,213, 220,231,238,248, 254,255,256,269, 277,282,289,294, 303,305,308,311, 315,324,325,326, 340,354,357,371, 374)
31	28	23	{28,20,12,4,27,19,11,3, 26,18,10,2,25,17,9,1, 24,16,8,0,23,15,7,30, 22,14,6,29,21,13,5}	(112,136,171,205, 221,235,252,291, 298,322,345,359, 360,388)
41	3	14	{3,17,31,4,18,32,5,19, 33,6,20,34,7,21,35,8, 22,36,9,23,37,10,24, 38,11,25,39,12,26,40, 13,27,0,14,28,1,15,29, 2,16,30}	(14,44,60,67,86,88, 122,129,137,203, 224,241,290,332, 333,367,373,375)
43	19	36	{19,12,5,41,34,27,20,13, 6,42,35,28,21,14,7,0,36, 29,22,15,8,1,37,30,23, 16,9,2,38,31,24,17,10, 3,39,32,25,18,11,4,40, 33,26}	(10,53,56,65,107, 135,207,226,350, 366)
47	38	45	{38,36,34,32,30,28,26, 24,22,20,18,16,14,12, 10,8,6,4,2,0,45,43,41, 39,37,35,33,31,29,27, 25,23,21,19,17,15,13, 11,9,7,5,3,1,46,44,42, 40}	(17,51,102,158, 172,189,206,247, 275,343,392)
53	10	1	{10,11,12,13,14,15,16,17, 18,19,20,21,22,23,24,25, 26,27,28,29,30,31,32,33, 34,35,36,37,38,39,40,41, 42,43,44,45,46,47,48,49, 50,51,52,0,1,2,3,4,5,6, 7,8,9}	(184,214,240,273, 339)

	Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
	59	3	46	{3,49,36,23,10,56,43,30, 17,4,50,37,24,11,57,44, 31,18,5,51,38,25,12,58, 45,32,19,6,52,39,26,13, 0,46,33,20,7,53,40,27,14, 1,47,34,21,8,54,41,28,15, 2,48,35,22,9,55,42,29,16}	(37,175)
	61	44	16	{44,60,15,31,47,2,18,34, 50,5,21,37,53,8,24,40, 56,11,27,43,59,14,30,46, 1,17,33,49,4,20,36,52,7, 23,39,55,10,26,42,58,13, 29,45,0,16,32,48,3,19,35, 51,4,22,38,54,7,25,41,57, 10,28}	(84)
(G)N=785	7	2	4	{2,6,3,0,4,1,5}	See (2) on page 85
	17	5	7	{5,12,2,9,16,6,13,3,10, 0,7,14,4,11,1,8,15}	See (3) on page 85,86
	23	1	16	{1,17,10,3,19,12,5,21, 14,7,0,16,9,2,18,11,4, 20,13,6,22,15,8}	See (4) on page 86
	31	29	23	{29,21,13,5,28,20,12,4, 27,19,11,3,26,18,10,2, 25,17,9,1,24,16,8,0, 23,15,7,30,22,14,6}	(53,70,147,163,171, 206,233,240,256, 301,332,333,485, 504,550,597,605,609, 674,766,767)
	41	40	14	{40,13,27,0,14,28,1,15, 29,2,16,30,3,17,31,4, 18,32,5,19,33,6,20,34, 7,21,35,8,22,36,9,23, 37,10,24,38,11,25,39, 12,26}	(10,11,18,28,31,79, 108,133,154,179, 182,212,235,261, 263,284,297,298, 315,317,325,354, 366,399,417,436, 448,469,499,522, 563,584,626,630, 672,723,745)
	43	20	36	{20,13,6,42,35,28,21,14, 7,0,36,29,22,15,8,1,37, 30,23,16,9,2,38,31,24, 17,10,3,39,32,25,18,11, 4,40,33,26,19,12,5,41, 34,27}	(77,91,172,205,248, 308,331,402,409, 416,471,478,486, 536,606,660,665, 675,688)

Prime (p)	c(mod p)	b(mod p)	The Sequence {c+ib} (mod p) i=0,1,2,...,max (p-1,N-1)	A(p)
47	30	45	{30,28,26,24,22,20,18,16, 14,12,10,8,6,4,2,0,45, 43,41,39,37,35,33,31,29, 27,25,23,21,19,17,15,13, 11,9,7,5,3,1,46,44,42, 40,38,36,34,32}	(2,9,45,74,94,214, 324,329,350,367, 371,375,422,444, 465,501,555,562, 620,623,637,647, 689)
53	46	1	{46,47,48,49,50,51,52,0, 1,2,3,4,5,6,7,8,9,10,11, 12,13,14,15,16,17,18,19, 20,21,22,23,24,25,26,27, 28,29,30,31,32,33,34,35, 36,37,38,39,40,41,42,43, 44,45}	(25,87,95,189,193, 210,252,269,352, 401,511,528,570, 639,655,711,758, 784)
59	42	46	{42,29,16,3,49,36,23,10, 56,43,30,17,4,50,37,24, 11,57,44,31,18,5,51,38, 25,12,58,45,32,19,6,52, 39,26,13,0,46,33,20,7, 53,40,27,14,1,47,34,21, 8,54,41,28,15,2,48,35, 22,9,55}	(44,137,164,494, 539,716)
61	19	16	{19,35,51,6,22,38,54,9, 25,41,57,12,28,44,60, 15,31,47,2,18,34,50,5, 21,37,53,8,24,40,56,11, 27,43,59,14,30,46,1,17, 33,49,4,20,36,52,7,23, 39,55,10,26,42,58,13,29, 45,0,16,32,48,3}	(80,490,654,669, 739)
67	37	38	{37,8,46,17,55,26,64,35, 6,44,15,53,24,62,33,4,42, 13,51,22,60,31,2,40,11, 49,20,58,29,0,38,9,47,18, 56,27,65,36,7,45,16,54, 25,63,34,5,43,14,52,23, 61,32,3,41,12,50,21,59, 30,1,39,10,48,19,57,28, 66}	(114,283)
79	20	41	{20,61,23,64,26,67,29, 70,32,73,35,76,38,0,41, 3,44,6,47,9,50,12,53,15, 56,18,59,21,62,24,65,27, 68,30,71,33,74,36,77,39, 1,42,4,45,7,48,10,51,13, 54,16,57,19,60,22,63,25, 66,28,69,31,72,34,75,37,78, 40,2,43,5,46,8,49,11,52,14, 55,17,58}	(724)

(1) (1,5,6,8,12,13,15,19,20,22,26,27,29,33,34,36,40,41,43,47,48,
50,54,55,57,61,62,64,68,69,71,75,76,78,82,83,85,89,90,92,96,97,99,103,
104,106,110,111,113,117,118,120,124,125,127,131,132,134,138,139,141,145,
146,148,152,153,155,159,160,162,166,167,169,173,174,176,180,181,183,187,
188,190,194,195,197,201,202,204,208,209,211,215,216,218,222,223,225,229,
230,232,236,237,239,243,244,246,250,251,253,257,258,260,264,265,267,271,
272,274,278,279,281,285,286,288,292,293,295,299,300,302,306,307,309,313,
314,316,320,321,323,327,328,330,334,335,337,341,342,344,348,349,351,355,
356,358,362,363,365,369,370,372,376,377,379,383,384,386,390,391,393)

(2) 1,5,6,8,12,13,15,19,20,22,26,27,29,33,34,36,40,41,43,47,48,50,
54,55,57,61,62,64,68,69,71,75,76,78,82,83,85,89,90,92,96,97,99,103,104,
106,110,111,113,117,118,120,124,125,127,131,132,134,138,139,141,145,146,
148,152,153,155,159,160,162,166,167,169,173,174,176,180,181,183,187,188,
190,194,195,197,201,202,204,208,209,211,215,216,218,222,223,225,229,230,
232,236,237,239,243,244,246,250,251,253,257,258,260,264,265,267,271,272,
274,278,279,281,285,286,288,292,293,295,299,300,302,306,307,309,313,314,
316,320,321,323,327,328,330,334,335,337,341,342,344,348,349,351,355,356,
358,362,363,365,369,370,373,376,377,379,383,384,386,390,391,393,397,398,
400,404,405,407,411,412,414,418,419,421,425,426,428,432,433,435,439,440,
442,446,447,449,453,454,456,460,461,463,467,468,470,474,475,477,481,482,
484,488,489,491,495,496,498,502,503,505,509,510,512,516,517,519,523,524,
526,530,531,533,537,538,540,544,545,547,551,552,554,558,559,561,565,566,
568,572,573,575,579,580,582,586,587,589,593,594,596,600,601,603,607,608,
610,614,615,617,621,622,624,628,629,631,635,636,638,642,643,645,649,650,
652,656,657,659,663,664,666,670,671,673,677,678,680,684,685,687,691,692,
694,698,699,701,705,706,708,712,713,715,719,720,722,726,727,729,733,734,
736,740,741,743,747,748,750,754,755,757,761,762,764,768,769,771,775,776,
778,782,783,785)

(3) 3,4,7,16,17,21,24,30,32,37,38,39,49,51,56,58,66,67,72,73,81,84,
88,98,100,101,102,105,107,109,115,119,122,123,126,135,136,140,143,149,
151,156,157,158,168,170,175,177,185,186,191,192,200,203,207,217,219,220,
221,224,226,228,234,238,241,242,245,254,255,259,262,268,270,275,276,277,
287,289,294,296,304,305,310,311,319,322,326,336,338,339,340,343,345,347,
353,357,360,361,364,373,374,378,381,387,389,394,395,396,406,408,413,415,
423,424,429,430,438,441,445,455,457,458,459,462,464,466,472,476,479,480,

(3) Continued 483,492,493,497,500,506,508,513,514,515,525,527,532, 534,542,543,548,549,557,560,564,574,576,577,578,581,583,585,591,595,598, 599,602,611,612,616,619,625,627,632,633,634,644,646,651,653,661,662,667, 668,676,679,683,693,695,696,697,700,702,704,710,714,717,718,721,730,731, 735,738,744,746,751,752,753,763,765,770,772,780,781

(4) (14,23,35,42,46,52,59,60,63,65,70,86,93,112,116,121,128,129, 130,142,144,150,161,165,178,184,196,198,199,213,227,231,247,249,266,273, 280,282,290,291,303,312,318,346,359,368,380,382,385,388,392,403,410,420, 427,431,434,437,443,450,451,452,473,487,507,518,520,521,529,535,541,546, 553,556,567,569,571,588,590,592,604,613,618,640,641,648,658,681,682,686, 690,703,707,709,725,728,732,737,742,749,756,759,760,773,774,779)

TABLE [V]

S.P.S. Program Designed to Test the Non-squareness of $n! + 1$

```
1000        DORG402
1010  PRIME DSB 5,50
1020  A     DS  25001
1030  B     DS  10051
1040  M     DS  2
1050  UB    DS  5
1060  P     DS  5
1070  W     DS  5
1080  TP    DS  5
1090  TEMP  DS  10
1100  N     DS  5
1140  BETA  DAC 50,PRIME                                       ,
1150        DAC 30,                       ,
1160  ZERO  DC  50,                                            ,
1170        DC  1,@
1171  BLANK DNB 1
1172        DNB 50
1173        DNB 29
1174        DC  1,@
1175  BET   DS  1
1176        DS  80
1180  START RNPTM-1
1200        RNPTPRIME-4
2010        BI  START1,00100
2020        TFM S1+11,PRIME
2030  S1    TF  TP,PRIME
2040  S5    TNF BETA+24,TP
2041        WACDBETA
2050        TF  P,TP
2060        SM  P,1
2070        MM  P,5,10
2071        SF  94
2080        TF  P,00098
```

```
2090        BTM SUBR
2100        TFM N,00001
2110        TFM TEMP,1
2120        TR  BET,BLANK
2130        TFM S6+6,BET
2140  INCRN AM  N,1
2150        C   N,UB
2160        BH  NEWP
2170        M   N,TEMP
2180        SF  00091
2190        TF  TEMP,00099
2200        LD  99,TEMP
2201        D   95,TP
2202        TF  TEMP,99
3050        TFM EQ+11,A
3060        S   EQ+11,TEMP
3070  EQ    BNF PRT,A
3080        TFM ALPHA+6,B
3090        S   ALPHA+6,N
3100  ALPHA SF  B
3110        B   INCRN
3120  PRT   AM  S6+6,7
3130  S6    TF  BET,N
3131        TF  *+30,S6+6
3132        SM  *+18,4
3133        CF  B
3140        CM  S6+6,BET+73
3150        BNH INCRN
3160        WNCDBET
3170        B   INCRN-24
4060  NEWP  WNCDBET
4090        BC2 TYPE
4110        SM  M,1,10
```

```
4120          CM   M,0,10
4130          BZ   START2
4140          AM   S1+11,5
4160   T6     TF   TP,S1+11,11
4170          TNF  BETA+24,TP
4171          WACDBETA
4180          TF   P,TP
4190          SM   P,1
4200          MM   P,5,10
4201          SF   94
5010          TF   P,00098
5020          BTM  SUBR
5030          TFM  N,00001
5040          TFM  TEMP,00001
5041          TR   BET,BLANK
5042          TFM  T3+6,BET
5050   REINC  AM   N,1
5060          C    N,UB
5070          BH   NEWP
5080          M    N,TEMP
5090          SF   00091
5100          TFM  90,
5120          D    95,TP
5130          TF   TEMP,99
5150   TEST   TFM  FL+11,B
5160          S    FL+11,N
5170   FL     BNF  REINC,B
5180          TFM  T1+11,A
5200          S    T1+11,TEMP
6010   T1     BNF  T2,A
6020          B    REINC
6050   T2     CF   FL+11,,6
6060          AM   T3+6,7
```

```
6070  T3     TF   BET,N
6071         TF   *+30,T3+6
6072         SM   *+18,4
6073         CF   B
6080         CM   T3+6,BET+73
6090         BNH REINC
6110         WNCDBET
6120         B    REINC-24
6170  TYPE   TFM T4+6,B-10000
6200  T4     WNCDB
7020         AM   T4+6,80
7030         CM   T4+6,B
7040         BNH T4
7050         H
7060  START3RNPTM-1
7080         RNPTPRIME-4
7090         TFM S1+11,PRIME
7100         B    T6
7110  START1TFM T7+6,B-10000
7120  T7     RNCDB
7130         AM   T7+6,80
7140         CM   T7+6,B
7150         BNH T7
7160         B    START3,,9
7170  START2TFM Q+11,B
7171  R      TR   BET,BLANK
7172         TFM Q3+6,BET
7173  Q      BNF NOFL,B
7174         TFM N,B
7175  Q1     S    N,Q+11
7176         AM   *+18,7
7177  Q3     TF   BET,N
7178         TF   *+30,Q3+6
```

```
7179        SM   *+18,4
7180        CF   B
7181        CM   Q3+6,BET+73
7182        BNH  NOFL
7183        WNCDBET
7184        SM   Q+11,1
7185        CM   Q+11,B-10000
7186        BNH  R
7187        B    START3
7188  NOFL  SM   Q+11,1
7189        CM   Q+11,B-10000
7190        BNL  Q
7191        WNCDBET
7192        B    START3
8010  SUBR  TFM  W,00000
8030        TFM  CLEAR+6,A-25000
8040  CLEAR TR   ,ZERO-48
8050        AM   CLEAR+6,50
8060        CM   CLEAR+6,A
8070        BNH  CLEAR
8110  INCW  AM   W,1
8120        C    W,P
8130        BH   OSQ
8140        M    W,W
8141        SF   91
8150        TF   TEMP,00099
8160        SM   TEMP,1
8204  DIVD  LD   99,TEMP
8205        D    95,TP
8206        TF   TEMP,99
9010  STOP  TFM  SET+6,A
9020        S    SET+6,TEMP
9030  SET   SF   A
```

```
9040        B    INCW
9050  OSQ   TF   TEMP,TP
9060        SM   TEMP,1
9070        TFM  *+30,A
9080        S    *+18,TEMP
9090        SF   A
9100        BB
9110        DENDSTART
```

TABLE [VI]

Results of Machine Computation with the Program of TABLE V

PRIME 10007

00003	00008	00010	00012	00015	00017	00019	00020	00021	00022	00023
00028	00030	00031	00032	00033	00034	00035	00037	00039	00041	00042
00043	00044	00046	00047	00048	00049	00051	00053	00055	00056	00058
00062	00063	00064	00067	00073	00074	00076	00077	00078	00079	00080
00082	00085	00086	00089	00091	00092	00096	00098	00101	00103	00104
00106	00112	00114	00118	00120	00129	00132	00135	00137	00138	00139
00140	00141	00142	00144	00145	00149	00150	00153	00154	00155	00156
00158	00160	00162	00163	00165	00166	00167	00169	00173	00174	00178
00179	00180	00181	00182	00185	00186	00187	00191	00192	00196	00198
00200	00201	00203	00205	00208	00209	00210	00211	00213	00218	00219
00220	00221	00224	00226	00228	00229	00231	00232	00234	00235	00236
00237	00238	00239	00240	00241	00242	00243	00246	00247	00248	00249
00252	00254	00255	00258	00260	00264	00265	00268	00271	00273	00276
00278	00279	00280	00281	00283	00284	00285	00287	00288	00289	00290
00293	00294	00295	00296	00301	00302	00304	00305	00307	00308	00309
00310	00311	00317	00319	00320	00321	00322	00323	00324	00325	00326
00328	00329	00330	00339	00340	00341	00342	00343	00344	00345	00348
00351	00352	00355	00358	00359	00361	00362	00363	00364	00365	00367
00369	00370	00371	00372	00377	00378	00379	00380	00382	00385	00386
00389	00392	00393	00395	00396	00398	00400	00401	00403	00405	00407
00413	00414	00415	00417	00426	00427	00428	00431	00436	00437	00439
00442	00447	00456	00461	00462	00463	00464	00470	00471	00472	00473
00474	00475	00476	00477	00478	00481	00486	00487	00488	00489	00490
00494	00497	00498	00499	00501	00503	00506	00509	00511	00513	00514
00515	00520	00524	00525	00527	00528	00535	00536	00537	00540	00541
00544	00545	00549	00551	00552	00559	00562	00563	00567	00568	00569
00570	00571	00573	00576	00577	00578	00579	00582	00587	00589	00590
00591	00593	00594	00595	00598	00599	00600	00601	00603	00604	00607
00610	00613	00615	00616	00619	00622	00633	00635	00636	00638	00640
00642	00643	00645	00649	00651	00652	00653	00655	00658	00660	00663
00667	00668	00670	00673	00676	00677	00678	00682	00685	00686	00687
00688	00689	00692	00695	00696	00699	00703	00705	00706	00707	00709

00714	00718	00722	00725	00726	00727	00730	00731	00732	00735	00737
00738	00739	00740	00741	00743	00745	00746	00748	00750	00751	00752
00754	00756	00758	00761	00762	00764	00765	00768	00769	00770	00773
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PRIME 10009

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PRIME 10037

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06081	06098	06099	06108	06111	06113	06118	06131	06153	06157	06172
06180	06185	06186	06191	06196	06204	06214	06229	06233	06242	06243
06272	06273	06274	06289	06296	06301	06309	06312	06325	06332	06335
06336	06339	06345	06347	06349	06356	06357	06362	06366	06373	06378
06382	06386	06396	06400	06407	06409	06410	06420	06422	06424	06436
06444	06445	06453	06463	06466	06473	06480	06490	06492	06497	06512
06519	06522	06538	06542	06544	06546	06552	06560	06561	06573	06575

06580	06592	06605	06609	06619	06622	06632	06639	06662	06664	06665
06682	06691	06692	06693	06694	06696	06697	06701	06709	06713	06746
06748	06757	06760	06773	06780	06786	06801	06802	06825	06826	06828
06832	06853	06869	06873	06874	06879	06880	06887	06894	06898	06903
06919	06921	06961	06962	06964	06970	06980	06981	06985	06993	06994
07012	07013	07026	07027	07036	07038	07041	07045	07052	07053	07062
07067	07071	07078	07103	07114	07120	07121	07135	07156	07164	07168
07173	07174	07190	07193	07204	07208	07256	07258	07264	07266	07274
07275	07280	07285	07292	07297	07300	07307	07309	07323	07334	07338
07339	07349	07358	07368	07375	07390	07399	07401	07415	07420	07441
07448	07458	07461	07471	07477	07482	07486	07489	07503	07511	07517
07521	07522	07529	07530	07531	07540	07541	07555	07568	07582	07593
07595	07598	07599	07602	07608	07625	07627	07633	07640	07669	07672
07675	07695	07714	07728	07733	07735	07747	07751	07759	07765	07774
07775	07796	07798	07799	07802	07817	07818	07822	07825	07827	07850
07853	07856	07868	07873	07874	07875	07889	07897	07916	07923	07930
07937	07946	07948	07956	07964	07966	07973	07980	07985	07988	07992
07995	07997	07999	08003	08007	08010	08025	08028	08030	08040	08052
08068	08071	08077	08078	08085	08094	08096	08098	08105	08108	08127
08132	08138	08141	08153	08165	08167	08175	08188	08197	08205	08206
08215	08216	08227	08236	08240	08243	08263	08272	08291	08294	08295
08304	08322	08369	08371	08372	08376	08382	08392	08404	08415	08417
08424	08425	08432	08433	08440	08445	08446	08451	08452	08453	08457
08462	08505	08513	08542	08550	08578	08592	08611	08615	08628	08631
08654	08655	08663	08695	08697	08707	08716	08750	08756	08768	08793
08803	08809	08811	08815	08827	08837	08839	08842	08850	08852	08858
08861	08865	08870	08886	08895	08913	08930	08950	08958	08959	08969
08983	08984	08998	09024	09030	09031	09033	09039	09053	09063	09069
09078	09080	09084	09108	09116	09127	09134	09153	09163	09172	09184
09185	09197	09208	09221	09227	09235	09244	09247	09274	09294	09300
09301	09302	09304	09327	09329	09377	09385	09389	09391	09392	09397
09427	09430	09431	09445	09446	09448	09456	09470	09472	09479	09489
09490	09491	09494	09495	09499	09500	09504	09516	09523	09532	09537

09539	09558	09582	09586	09591	09595	09598	09616	09619	09625	09627
09628	09639	09648	09675	09679	09680	09691	09695	09701	09710	09725
09727	09732	09750	09752	09757	09758	09764	09771	09772	09773	09783
09785	09806	09811	09821	09823	09826	09832	09845	09853	09856	09868
09873	09881	09883	09887	09891	09892	09902	09912	09922	09928	09932
09941	09946	09951	09962	09963	09983	09991				

PRIME 10039

00027	00052	00081	00084	00097	00107	00110	00146	00161	00197	00245
00261	00292	00297	00299	00300	00313	00314	00315	00333	00349	00375
00381	00399	00404	00409	00410	00422	00441	00453	00469	00479	00483
00505	00519	00523	00530	00533	00538	00543	00606	00614	00617	00624
00629	00634	00641	00684	00708	00719	00736	00771	00780	00782	00788
00800	00814	00818	00827	00837	00860	00882	00888	00896	00899	00921
00923	00931	00934	00961	00978	00982	00987	00994	00997	01004	01035
01037	01052	01058	01084	01095	01104	01123	01172	01173	01185	01191
01243	01255	01306	01309	01310	01315	01332	01346	01387	01469	01470
01493	01499	01523	01545	01548	01565	01587	01592	01602	01605	01656
01690	01711	01729	01734	01763	01766	01774	01800	01801	01810	01814
01842	01854	01862	01872	01893	01908	01913	01920	01931	01947	01949
01952	01973	02018	02020	02051	02055	02067	02072	02081	02085	02123
02130	02158	02160	02164	02204	02223	02252	02254	02263	02319	02329
02345	02354	02364	02373	02383	02401	02405	02409	02448	02469	02472
02476	02492	02529	02574	02577	02596	02608	02645	02648	02665	02668
02670	02681	02682	02691	02732	02735	02748	02750	02758	02760	02761
02804	02807	02817	02840	02855	02885	02915	02916	02929	02948	02959
02977	03009	03014	03035	03080	03097	03121	03126	03135	03158	03163
03184	03209	03222	03245	03249	03252	03272	03273	03278	03293	03294
03303	03337	03418	03424	03444	03447	03474	03481	03506	03508	03513
03589	03615	03622	03635	03678	03713	03729	03741	03752	03801	03847
03851	03855	03868	03888	03905	03919	03937	03938	03961	03988	03996
04000	04019	04038	04040	04050	04071	04091	04104	04142	04163	04179
04215	04230	04247	04271	04277	04300	04313	04314	04335	04336	04342
04343	04345	04370	04371	04373	04374	04390	04398	04400	04409	04454

04462	04487	04517	04528	04529	04531	04536	04542	04576	04604	04672
04675	04714	04721	04738	04750	04763	04773	04777	04787	04795	04826
04832	04849	04909	04911	04938	04949	04976	04978	04986	04995	04996
05002	05011	05024	05035	05038	05084	05128	05133	05137	05149	05163
05191	05196	05216	05223	05224	05233	05237	05256	05258	05272	05285
05293	05299	05303	05319	05321	05330	05337	05354	05388	05393	05421
05425	05429	05431	05470	05484	05492	05498	05508	05524	05565	05583
05639	05644	05649	05653	05693	05737	05740	05744	05758	05774	05792
05797	05829	05866	05871	05899	05919	05957	05980	06011	06013	06030
06055	06068	06074	06117	06133	06145	06159	06163	06182	06198	06201
06208	06216	06221	06245	06271	06285	06287	06333	06340	06352	06375
06394	06429	06430	06438	06443	06457	06477	06508	06511	06531	06539
06574	06614	06667	06675	06705	06720	06740	06770	06775	06785	06824
06833	06839	06870	06902	06907	06908	06941	06946	06954	06991	07007
07029	07049	07065	07069	07070	07076	07102	07119	07125	07126	07171
07182	07189	07197	07205	07210	07224	07227	07235	07253	07290	07295
07311	07320	07381	07385	07395	07409	07412	07450	07464	07491	07508
07512	07514	07533	07547	07552	07562	07585	07601	07632	07648	07659
07673	07679	07699	07721	07725	07732	07736	07742	07744	07792	07804
07808	07826	07848	07867	07877	07890	07892	07934	07935	07947	07950
07983	07991	07994	08005	08012	08048	08070	08090	08099	08119	08144
08158	08168	08172	08185	08251	08276	08292	08350	08380	08396	08410
08416	08434	08439	08442	08473	08520	08527	08532	08535	08613	08636
08643	08645	08650	08669	08678	08702	08708	08722	08738	08785	08789
08791	08830	08834	08859	08863	08868	08874	08883	08902	08906	08914
08931	08939	08963	09006	09038	09041	09043	09058	09059	09086	09100
09104	09119	09121	09130	09133	09167	09182	09192	09206	09211	09217
09226	09261	09263	09277	09290	09296	09308	09312	09332	09343	09355
09376	09414	09419	09425	09426	09437	09460	09484	09550	09567	09571
09573	09589	09605	09617	09647	09683	09684	09690	09697	09698	09718
09737	09744	09745	09774	09777	09804	09819	09855	09860	09870	09893
09906	09927	09944	09952	09980	09998					

PRIME 10061

00025	00125	00177	00215	00216	00222	00259	00266	00274	00346	00390
00451	00493	00521	00547	00548	00550	00554	00580	00648	00659	00675
00744	00776	00779	00787	00801	00929	01024	01033	01044	01080	01105
01117	01132	01140	01164	01199	01214	01229	01241	01276	01298	01302
01307	01311	01323	01343	01375	01376	01392	01415	01460	01597	01615
01668	01798	01807	01885	01933	01940	02019	02029	02049	02071	02089
02091	02105	02121	02149	02155	02161	02187	02188	02215	02232	02304
02347	02367	02372	02392	02406	02411	02421	02435	02444	02446	02453
02457	02462	02530	02582	02586	02587	02597	02601	02615	02616	02663
02677	02695	02780	02822	02842	02897	02899	02989	03028	03067	03101
03131	03145	03160	03207	03221	03235	03277	03304	03312	03327	03368
03408	03430	03456	03468	03487	03521	03593	03604	03605	03742	03761
03829	03846	03867	03897	03957	03997	04055	04101	04106	04141	04182
04202	04210	04216	04244	04288	04297	04299	04303	04325	04339	04354
04356	04387	04391	04431	04459	04555	04562	04640	04644	04650	04681
04691	04766	04812	04840	04856	04863	04892	04896	04945	05066	05173
05199	05205	05262	05271	05346	05389	05432	05463	05522	05526	05533
05535	05550	05572	05593	05620	05634	05636	05694	05704	05839	05875
05925	05927	05940	05945	05992	06078	06096	06126	06170	06205	06215
06266	06299	06379	06387	06395	06408	06427	06455	06601	06612	06626
06659	06676	06698	06712	06734	06742	06754	06766	06799	06818	06864
06871	06899	06901	06925	06966	06967	07000	07031	07207	07249	07341
07350	07416	07429	07474	07475	07504	07542	07596	07662	07687	07698
07707	07711	07741	07813	07832	07833	07847	07866	07883	07909	07969
08029	08054	08107	08166	08187	08200	08222	08257	08264	08271	08275
08287	08288	08299	08391	08510	08518	08529	08547	08606	08623	08626
08665	08710	08764	08779	08794	08872	08907	08929	08977	08994	08995
09027	09035	09037	09044	09049	09071	09072	09098	09138	09159	09179
09272	09316	09394	09407	09508	09530	09556	09593	09601	09671	09682
09709	09715	09770	09803	09814	09822	09896	09938	09947		

PRIME 10067

00134	00225	00306	00419	00420	00502	00565	00630	00639	00693	00716
00825	00881	00924	01001	01089	01170	01211	01222	01393	01500	01629

01688	01849	01852	02119	02137	02189	02309	02388	02581	02811	02931
02951	03005	03034	03038	03094	03139	03149	03151	03242	03269	03493
03535	03541	03544	03557	03561	03636	03646	03684	03699	03723	03903
03904	04006	04024	04062	04209	04211	04228	04278	04439	04446	04481
04508	04514	04695	04724	04753	04778	04796	04797	04828	04872	04912
04951	04988	05190	05197	05202	05267	05341	05363	05413	05420	05483
05491	05495	05539	05548	05831	05873	05962	05998	06029	06136	06149
06305	06390	06576	06644	06657	06730	06750	06769	06863	06868	06911
06990	07040	07043	07051	07063	07098	07148	07187	07250	07330	07335
07357	07430	07465	07483	07525	07565	07567	07809	07857	07861	07908
07940	08063	08575	08635	08769	08801	08854	08921	08927	08936	09042
09045	09135	09257	09268	09369	09390	09410	09447	09538	09549	09703
09711	09778	09788	09830	09943						

PRIME 10069

00202	00263	00459	01131	01148	01228	01389	01687	01735	01837	01936
01993	02030	02062	02176	02199	02317	02442	02533	02590	02595	02756
02820	02827	02942	03183	03227	03333	03505	03733	03735	03792	03975
03990	04266	04309	04471	04549	04639	05013	05049	05297	05568	05708
05807	05838	05931	06066	06124	06168	06451	06543	06638	06876	06951
07160	07188	07231	07257	07738	07770	07945	08019	08037	08044	08089
08139	08267	08274	08312	08630	08760	09003	09083	09351	09786	09920
09936										

PRIME 10079

00070	00071	02257	02290	02523	02557	02610	03318	03396	03596	04022
04348	04816	04998	05125	05246	05607	05966	06286	07493	07652	07884
08519	08562	08802	09581	09837	09841					

PRIME 10091

00094	00423	02606	03124	03842	04021	04267	04414	04445	04557	04964
04992	06810	06972	07347	07380	07858	08103	08713	08996	09160	09646

PRIME 10093

00647	00792	01420	01999	02154	02239	04685	05243	05675	05937	06054
083[illegible]7	09093	09180								

```
PRIME   10099
   00075  01382  03978  05494  06989  07647  08554
PRIME   10103
   00834
PRIME   10111
   00347  02778  03223  04966  05103

   00004  00005  00007
```

TABLE [VII]

S.P.S. Program to Test the Non-squareness of T_n

```
1010       DORG402
1020 PRIME DSB 2,24
1030 Q     DS  101
1040 B     DS  10051
1050 G     DS  2
1060 AR    DSB I,10001
1070 M     DS  2
1080 P     DS  2
1090 W     DS  2
1100 TP    DS  2
1110 TEMP  DS  5
1120 N     DS  5
1130 U     DS  2
1140 UB    DS  5
1150 LIM   DS  2
1160 ADD   DS  5
1170 J     DS  5
1180 K     DS  5
1190 STOR  DS  3
1200 PER   DS  5
1201 ALPHA DS  2
2010 D     DS  5
2020 BETA  DAC 50,PRIME
2030       DAC 30,
2040 ZERO  DC  50,
2050       DC  1,@
2060 BLANK DNB 1
2070       DNB 50
2080       DNB 29
2090       DC  1,@
2100 BET   DS  1
2110       DS  80
2120 START RNPTU-1
```

```
2130            RNPTPRIME-1
2140            TFM *+30,G
2150            AM  *+18,2
2160  S13       TFM G,1,10
2170            TF  *+30,S13+6
2180            AM  *+18,2
2190            TFM G,1,10
2200            TFM *+23,PRIME
3010  S23       TF  P,PRIME
3020            BTM SUBR
3030            TFM J,
3040            TFM S14+11,G
3050            AM  S14+11,2
3060            TFM *+35,Q
3070  S14       S   *+23,G
3080            BNF S15,Q
3090            TFM *+30,B
3100            S   *+18,J
3110            SF  B
3120  S15       AM  J,1
3130            C   J,PER
3140            BNH S14-24
3150            TFM J,
3160            TFM *+23,B
3170  S18       BNF S17,B
3180            TF  D,J
3190  S16       A   D,PER
3200            AM  D,1
4010            C   D,UR
4020            BH  S17
4030            TFM *+30,B
4040            S   *+18,D
4050            SF  B
```

```
4060         B    S16
4070  S17    AM   J,1
4080         SM   S18+11,1
4090         C    J,PER
4100         BNH  S18
4110         TNF  BETA+24,P
4130         WACDBETA
4140         TFM  J,
4150         SM   J,1
4160         TFM  S21+11,B+1
4170         TR   BET,BLANK
4180         TFM  S20+18,BET
4190  S19    AM   J,1
4200         C    J,UB
5010         BH   S22
5020         SM   *+23,1
5030  S21    BNF  S20,B
5040         B    S19
5050  S20    AM   *+18,7
5060         TF   BET,J
5070         TF   *+30,S20+18
5080         SM   *+18,4
5090         CF   BET
5100         CM   S20+18,BET+73
5110         BNH  S19
5120         WNCDBET
5130         B    S19-24
5140  S22    WNCDBET
5150         BC1  S31
5160         SM   U,1,10
5170         CM   U,,10
5180         BZ   OUTP
5190         AM   S23+11,2
```

```
5200          TF   P,S23+11,11
6010          TNF  BETA+24,P
6020          BTM  SUBR
6060          WACDBETA
6070          TF   D,PER
6080          AM   D,1
6090          TR   BET,BLANK
6100          TFM  S29+6,BET
6110          TFM  J,
6120          TFM  *+23,B
6130   S26    BNF  S27,B
6140          LD   99,J
6150          D    95,D
6160          TF   K,99
6170          TFM  S30+11,G
6180          A    S30+11,K
6190          A    S30+11,K
6200          AM   S30+11,2
7010          TFM  S30+23,G
7020   S30    S    S30+23,G
7030          BNF  S29,Q
7040   S27    AM   J,1
7050          C    J,UB
7060          BH   S22
7070          SM   S26+11,1
7080          B    S26
7090   S28    TFM  *+30,B
7100          S    *+18,J
7110          CF   B
7120          AM   *+18,7
7130   S29    TF   RET,J
7131          TF   *+30,S29+6
7140          SM   *+18,4
```

```
7150          CF   BET
7160          CM   S29+6,BET+73
7170          BNH  S27
7180          WNCDBET
7190          TR   BET,BLANK
7200          TFM  S29+6,BET
8010          B    S27
8020   S31    TFM  S32+11,B
8030          TR   BET,BLANK
8040          TFM  S33+6,BET
8050   S32    BNF  S34,B
8060          TFM  J,B
8070          S    J,S32+11
8080          AM   *+18,7
8090   S33    TF   BET,J
8100          TF   *+30,S33+6
8110          SM   *+18,4
8120          CF   BET
8130          CM   S33+6,BET+73
8140          BNH  S34
8150          WNCDBET
8160          SM   S32+11,1
8170          CM   S32+11,B-10000
8180          BNL  S31+12
8190   S41    BNC3S42
8191          TFM  S40+6,B-10000
8192   S40    TR   ,ZERO-48
8193          AM   S40+6,50
8195          CM   S40+6,B
8196          BNH  S40
8197   S42    H
8200   S34    SM   S32+11,1
9010          CM   S32+11,B-10000
```

```
9020        BNL S32
9030        WNCDBET
9040        B   S41
9050  OUTP  BNC2S31
9060        RNPTU-1
9070        RNPTPRIME-1
9080        TFM S23+11,PRIME
9090        B   S22+24
10010 SUBR  TF  PER,P
10020       SM  PER,1,10
10030       TFM N,1,10
10040       TFM S1+11,G
10050       AM  S1+11,2
10060 S1    M   N,G
10070       TF  TEMP,99
10080       AM  S1+11,2
10090       A   TEMP,S1+11,11
10100       LD  99,TEMP
10110       D   98,P
10120       AM  S1+11,2
10130       TF  S1+11,99,6
10140       AM  N,1,10
10150       SM  S1+11,2
10160       C   PER,N
10170       BH  S1
13200 SUB2  TF  TP,P
14010       SM  TP,1,10
14020       MM  TP,5,10
14030       SF  97
14040       TF  TP,98
14050       TFM W,,10
14060       TFM CLEAR+6,Q-100
14070 CLEAR TP  ,ZERO-48
```

```
14080          AM   CLEAR+6,50
14090          CM   CLEAR+6,Q
14100          BNH  CLEAR
14110          SF   Q
14120   INCW   AM   W,1,10
14130          C    W,TP
14140          BNH  *+24
14150          BB
14160          M    W,W
14170          SF   96
14180          TF   TEMP,99
14190          LD   99,TEMP
14200          D    98,P
15010          TF   TEMP,99
15020          TFM  SET+6,Q
15030          S    SET+6,TEMP
15040   SET    SF   Q
15050          B    INCW
15060          DENDSTART
```

TABLE [VIII]

Results of Machine Computation with the Program of TABLE VII

PRIME	03									
00002	00005	00008	00011	00014	00017	00020	00023	00026	00029	00032
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PRIME 05

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00252	00262	00267	00277	00282	00292	00297	00307	00312	00322	00327
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02152	02157	02167	02172	02182	02187	02197	02202	02212	02217	02227
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02647	02652	02662	02667	02677	02682	02692	02697	02707	02712	02722
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04212	04222	04227	04237	04242	04252	04257	04267	04272	04282	04287
04297	04302	04312	04317	04327	04332	04342	04347	04357	04362	04372
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05202	05212	05217	05227	05232	05242	05247	05257	05262	05272	05277
05287	05292	05302	05307	05317	05322	05332	05337	05347	05352	05362
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05452	05457	05467	05472	05482	05487	05497	05502	05512	05517	05527
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05862	05872	05877	05887	05892	05902	05907	05917	05922	05932	05937
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06112	06117	06127	06132	06142	06147	06157	06162	06172	06177	06187
06192	06202	06207	06217	06222	06232	06237	06247	06252	06262	06267
06277	06282	06292	06297	06307	06312	06322	06327	06337	06342	06352
06357	06367	06372	06382	06387	06397	06402	06412	06417	06427	06432
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06607	06612	06622	06627	06637	06642	06652	06657	06667	06672	06682
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07432	07437	07447	07452	07462	07467	07477	07482	07492	07497	07507
07512	07522	07527	07537	07542	07552	07557	07567	07572	07582	07587
07597	07602	07612	07617	07627	07632	07642	07647	07657	07662	07672
07677	07687	07692	07702	07707	07717	07722	07732	07737	07747	07752
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07842	07852	07857	07867	07872	07882	07887	07897	07902	07912	07917
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08007	08017	08022	08032	08037	08047	08052	08062	08067	08077	08082
08092	08097	08107	08112	08122	08127	08137	08142	08152	08157	08167
08172	08182	08187	08197	08202	08212	08217	08227	08232	08242	08247
08257	08262	08272	08277	08287	08292	08302	08307	08317	08322	08332
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08502	08512	08517	08527	08532	08542	08547	08557	08562	08572	08577
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09987	09997									

PRIME 07

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00193	00195	00201	00208	00214	00216	00223	00228	00229	00235	00243
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00676	00678	00684	00685	00690	00691	00699	00705	00706	00711	00718
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00774	00775	00781	00783	00789	00790	00795	00796	00804	00810	00811
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PRIME 11

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08155	08164	08179	08190	08193	08199	08221	08226	08241	08248	08254
08256	08263	08274	08281	08289	08296	08298	08311	08325	08331	08340
08344	08353	08358	08373	08380	08386	08388	08395	08410	08421	08424
08428	08430	08443	08463	08479	08485	08494	08505	08520	08529	08556
08571	08575	08578	08584	08589	08604	08611	08619	08626	08641	08655
08659	08661	08674	08683	08688	08694	08703	08710	08716	08718	08725

08736	08743	08751	08758	08760	08773	08793	08806	08809	08815	08820
08835	08848	08850	08883	08886	08890	08905	08914	08919	08925	08934
08941	08949	08956	08974	08989	08991	09004	09018	09024	09033	09040
09046	09051	09066	09073	09079	09081	09088	09103	09114	09121	09123
09136	09145	09150	09156	09165	09178	09180	09198	09205	09213	09220
09235	09249	09255	09264	09268	09271	09304	09310	09319	09334	09345
09348	09354	09376	09381	09396	09403	09409	09411	09418	09429	09436
09444	09451	09453	09466	09480	09486	09495	09499	09508	09513	09528
09535	09541	09543	09550	09565	09576	09579	09583	09585	09598	09618
09634	09640	09649	09660	09675	09684	09711	09726	09730	09733	09739
09744	09759	09766	09774	09781	09796	09810	09814	09816	09829	09838
09843	09849	09858	09865	09871	09873	09880	09891	09898	09906	09913
09915	09928	09948	09961	09964	09970	09975	09990			
PRIME	13									
00010	00036	00045	00049	00058	00063	00084	00085	00093	00100	00106
00115	00126	00150	00154	00175	00184	00205	00210	00219	00231	00241
00253	00280	00283	00309	00318	00331	00360	00366	00373	00379	00388
00399	00414	00423	00436	00448	00451	00465	00478	00483	00505	00513
00514	00535	00540	00553	00555	00561	00568	00583	00591	00595	00604
00630	00639	00646	00660	00661	00696	00700	00709	00738	00751	00756
00778	00786	00799	00808	00813	00826	00828	00841	00843	00855	00868
00891	00903	00925	00934	00945	00946	00960	00969	00973	00990	01008
01011	01023	01024	01050	01059	01081	01086	01099	01101	01114	01116
01129	01141	01155	01176	01185	01198	01206	01218	01228	01233	01246
01254	01255	01270	01276	01281	01284	01309	01323	01345	01354	01374
01375	01380	01389	01393	01449	01471	01479	01501	01506	01515	01519
01528	01536	01540	01543	01554	01569	01570	01584	01596	01605	01606
01618	01653	01660	01666	01675	01683	01701	01710	01723	01738	01765
01774	01779	01800	01801	01809	01816	01848	01855	01869	01870	01878
01891	01900	01921	01926	01933	01935	01939	01948	01969	01974	01983
01996	01998	02025	02038	02065	02073	02086	02089	02095	02100	02115
02128	02130	02164	02178	02194	02199	02208	02221	02229	02233	02256
02269	02271	02284	02298	02299	02310	02311	02320	02346	02355	02359

02368	02373	02376	02388	02394	02401	02403	02416	02425	02464	02485
02493	02494	02515	02520	02529	02541	02544	02563	02571	02584	02593
02619	02628	02641	02661	02674	02676	02689	02698	02724	02739	02740
02758	02766	02775	02779	02788	02793	02815	02823	02830	02845	02856
02871	02893	02901	02905	02914	02934	02940	02949	02970	02971	03010
03013	03025	03039	03048	03061	03066	03088	03090	03096	03103	03109
03118	03129	03153	03165	03178	03195	03208	03213	03220	03234	03235
03244	03256	03270	03283	03285	03286	03300	03321	03325	03334	03360
03363	03369	03376	03391	03426	03439	03451	03454	03465	03468	03481
03486	03495	03508	03516	03538	03543	03556	03558	03564	03571	03585
03586	03594	03598	03633	03649	03655	03663	03664	03675	03685	03690
03699	03703	03741	03754	03759	03780	03781	03789	03811	03816	03829
03831	03844	03846	03850	03858	03871	03880	03894	03906	03915	03928
03948	03949	03963	03976	03985	03993	04000	04011	04014	04026	04053
04075	04084	04089	04104	04110	04119	04144	04158	04179	04180	04188
04201	04209	04210	04221	04231	04236	04245	04249	04258	04273	04279
04284	04300	04326	04335	04348	04375	04378	04383	04390	04396	04405
04440	04455	04474	04495	04504	04509	04518	04531	04539	04543	04546
04573	04599	04608	04609	04621	04630	04650	04656	04663	04665	04669
04678	04686	04704	04713	04726	04741	04755	04768	04795	04803	04804
04819	04825	04830	04845	04851	04858	04873	04881	04894	04903	04924
04929	04936	04938	04950	04951	04986	04999	05001	05028	05041	05050
05068	05076	05085	05089	05098	05103	05118	05131	05133	05145	05155
05181	05211	05215	05224	05236	05250	05259	05274	05280	05301	05313
05314	05323	05349	05358	05365	05371	05376	05379	05391	05404	05406
05419	05428	05470	05475	05488	05496	05505	05518	05523	05544	05545
05560	05566	05574	05596	05610	05631	05635	05644	05664	05665	05670
05679	05701	05743	05761	05769	05778	05791	05796	05805	05818	05820
05826	05833	05848	05859	05860	05874	05895	05896	05904	05908	05925
05943	05950	05965	05973	05974	05995	06000	06013	06016	06028	06051
06055	06064	06069	06090	06091	06093	06099	06106	06121	06156	06160
06168	06181	06190	06198	06211	06216	06223	06225	06238	06259	06273
06286	06288	06289	06303	06315	06324	06328	06363	06366	06379	06385

06394	06405	06420	06429	06454	06468	06471	06484	06489	06498	06511
06519	06520	06541	06546	06559	06561	06574	06588	06589	06601	06610
06636	06645	06658	06666	06678	06688	06693	06706	06715	06744	06783
06784	06805	06814	06819	06834	06849	06853	06861	06874	06883	06909
06918	06931	06940	06951	06966	06975	06979	06988	06996	07003	07014
07029	07030	07056	07065	07078	07105	07113	07120	07135	07161	07183
07191	07204	07213	07224	07234	07239	07248	07260	07261	07276	07290
07303	07315	07329	07338	07351	07360	07378	07380	07381	07386	07393
07395	07399	07408	07443	07455	07458	07485	07498	07521	07525	07534
07546	07549	07560	07575	07576	07590	07611	07624	07633	07653	07659
07666	07668	07681	07689	07716	07729	07744	07758	07771	07780	07785
07798	07806	07815	07828	07833	07848	07854	07861	07875	07876	07884
07906	07939	07941	07945	07953	07954	07975	07980	07989	08004	08031
08044	08053	08071	08079	08088	08095	08101	08106	08121	08134	08136
08148	08158	08170	08184	08200	08205	08214	08218	08235	08239	08253
08275	08283	08290	08304	08305	08316	08326	08361	08365	08368	08374
08379	08394	08400	08409	08431	08470	08473	08478	08491	08499	08500
08508	08521	08526	08535	08548	08550	08563	08569	08590	08599	08613
08625	08634	08638	08668	08673	08680	08695	08704	08730	08745	08746
08764	08781	08785	08794	08799	08808	08821	08823	08829	08836	08851
08863	08898	08899	08911	08920	08928	08940	08946	08953	08955	08968
08976	08998	09003	09016	09019	09031	09045	09054	09058	09093	09094
09096	09109	09115	09124	09135	09159	09163	09171	09184	09193	09201
09214	09219	09226	09228	09240	09241	09250	09276	09289	09291	09306
09318	09331	09340	09366	09369	09375	09388	09408	09423	09445	09460
09471	09474	09501	09514	09523	09544	09549	09564	09570	09591	09600
09604	09613	09639	09648	09655	09661	09669	09670	09681	09691	09696
09705	09709	09718	09760	09765	09786	09795	09808	09835	09850	09856
09864	09886	09900	09921	09934	09943	09954	09955	09969	09978	09991
09999										

PRIME 17

00016	00021	00030	00078	00129	00135	00183	00220	00225	00234	00276
00316	00330	00364	00381	00415	00421	00429	00441	00463	00469	00520

00588	00616	00619	00645	00679	00693	00744	00883	00931	00976	01030
01044	01053	01078	01143	01149	01200	01240	01248	01288	01305	01330
01339	01353	01435	01438	01444	01486	01534	01563	01585	01591	01611
01639	01690	01704	01716	01750	01815	01849	01911	01914	01954	01968
02005	02010	02016	02053	02101	02124	02163	02166	02200	02214	02254
02353	02410	02430	02458	02478	02509	02614	02625	02634	02656	02716
02733	02761	02821	02835	02838	02863	02920	02991	03019	03033	03076
03081	03124	03138	03186	03223	03319	03396	03424	03433	03444	03475
03501	03523	03549	03580	03591	03600	03648	03696	03739	03795	03838
03886	03934	03943	04005	04033	04056	04161	04203	04243	04291	04308
04356	04368	04399	04410	04419	04441	04515	04566	04594	04606	04614
04620	04623	04671	04705	04719	04753	04770	04810	04818	04861	04900
04909	04971	04980	05005	05008	05019	05056	05070	05104	05175	05266
05320	05334	05413	05433	05439	05461	05481	05490	05538	05580	05589
05643	05694	05719	05728	05736	05776	05824	05838	05841	05875	05881
05923	05929	05980	05994	06079	06141	06204	06226	06280	06300	06391
06399	06436	06456	06490	06504	06555	06583	06603	06643	06651	06660
06685	06748	06765	06790	06799	06841	06889	06898	06946	06960	07008
07045	07051	07059	07150	07164	07246	07309	07323	07371	07428	07450
07470	07476	07479	07513	07518	07569	07609	07623	07626	07674	07708
07714	07756	07765	07773	07813	07864	07870	07938	07960	07969	07983
08011	08074	08085	08130	08176	08269	08295	08323	08346	08436	08445
08493	08533	08541	08598	08640	08646	08731	08779	08788	08830	08844
08856	08878	08884	08904	08935	08983	09009	09060	09108	09261	09298
09303	09346	09360	09394	09439	09459	09465	09493	09516	09558	09621
09646	09663	09703	09723	09745	09751	09754	09768	09859	09870	09901
09949										

PRIME 19

00091	00099	00148	00238	00261	00289	00315	00346	00430	00498	00525
00528	00546	00610	00694	00714	00715	00736	00745	00771	00793	00819
00850	00870	00876	00885	00924	00954	01009	01066	01074	01123	01144
01171	01239	01275	01303	01360	01408	01416	01429	01459	01473	01638
01668	01695	01743	01759	01771	01834	01836	01858	01864	01893	01990

02170	02263	02313	02409	02436	02443	02500	02548	02586	02599	02626
02670	02683	02691	02709	02731	02746	02751	02808	02824	02865	02898
02955	02956	03004	03006	03054	03055	03069	03145	03241	03264	03279
03318	03340	03354	03355	03384	03411	03453	03510	03565	03640	03726
03745	03774	03783	03796	03853	03888	03916	04020	04081	04095	04125
04146	04165	04194	04251	04306	04315	04363	04438	04476	04480	04488
04524	04551	04564	04581	04735	04746	04840	04914	04935	04944	04993
05026	05049	05083	05125	05134	05140	05160	05208	05239	05265	05316
05335	05343	05398	05400	05446	05448	05455	05463	05503	05533	05628
05673	05721	05734	05749	05866	05901	05958	05959	06006	06084	06139
06148	06189	06196	06205	06244	06253	06310	06358	06414	06475	06513
06531	06616	06673	06699	06700	06709	06721	06798	06825	06930	07015
07021	07023	07063	07080	07098	07129	07140	07155	07254	07281	07311
07336	07344	07345	07414	07441	07444	07554	07591	07630	07686	07710
07743	07800	07821	07840	07843	07899	08029	08086	08115	08128	08143
08163	08185	08191	08220	08260	08389	08451	08466	08484	08514	08554
08583	08676	08865	08869	08913	08926	08961	08970	09010	09039	09075
09130	09151	09208	09229	09283	09324	09325	09333	09339	09390	09415
09438	09529	09534	09571	09586	09606	09625	09628	09654	09724	09738
09780	09789	09844	09894	09933	09985	09996				

PRIME 23

00043	00066	00073	00121	00133	00190	00198	00199	00274	00294	00351
00385	00406	00408	00456	00549	00654	00681	00723	00780	00814	00861
00918	00940	00975	01039	01045	01108	01156	01158	01165	01191	01204
01213	01261	01338	01365	01386	01464	01470	01561	01578	01620	01624
01708	01746	01785	01884	01906	01941	01963	02068	02079	02080	02131
02145	02179	02205	02241	02296	02304	02331	02340	02361	02383	02551
02590	02640	02695	02718	02850	02929	02964	03046	03123	03136	03160
03171	03180	03193	03201	03228	03333	03349	03418	03459	03514	03528
03550	03615	03619	03684	03718	03769	03873	03879	03895	03901	03930
03970	04069	04111	04126	04159	04224	04264	04293	04320	04333	04341
04389	04411	04425	04434	04489	04641	04683	04698	04711	04788	04839
04896	04966	05034	05035	05043	05148	05166	05169	05173	05230	05281

05299	05356	05386	05434	05511	05530	05551	05593	05595	05629	05650
05698	05754	05764	05811	06009	06036	06058	06105	06126	06135	06174
06183	06231	06321	06343	06421	06435	06469	06478	06526	06553	06618
06630	06720	06735	06828	06891	06904	06919	06933	06973	07036	07128
07149	07168	07171	07219	07318	07366	07435	07483	07540	07584	07644
07645	07696	07701	07723	07738	07749	07791	07903	07920	07996	08008
08046	08059	08064	08151	08169	08206	08284	08359	08401	08403	08415
08416	08449	08458	08506	08596	08610	08620	08631	08689	08709	08715
08778	08800	08841	08893	08988	09025	09030	09100	09129	09186	09243
09256	09315	09355	09424	09450	09520	09555	09633	09793	09831	09885
09919	09940	09963	09976							

PRIME 29

00051	00120	00168	00304	00324	00393	00729	00759	00835	00898	00910
00913	01290	01396	01485	01521	01548	01603	01633	01669	01794	01851
01899	01981	02023	02046	02058	02278	02326	02431	02445	02460	02508
02604	02703	02725	02760	02926	02989	03003	03024	03250	03388	03409
03531	03670	03706	03825	03921	03978	03979	04018	04216	04579	04588
04636	04693	04720	04740	04749	04854	04984	05013	05071	05188	05244
05329	05364	05565	05659	05686	05706	05775	05785	05853	05910	05985
06154	06240	06258	06295	06330	06336	06534	06568	06594	06625	06750
06751	06820	06916	06924	06993	07084	07114	07206	07245	07353	07359
07491	07855	07890	07974	08038	08073	08211	08233	08310	08319	08464
08568	08653	08724	08766	08871	08995	09061	09144	09166	09199	09285
09361	09373	09430	09478	09688	09690	09753	09775	09801	09828	09984

PRIME 31

00450	00484	01134	01431	02031	02530	02859	03613	03748	03913	04048
05554	05763	06786	06856	07050	07210	07296	07639	07675	08016	08536
08605	08739	09936								

PRIME 37

00511	00624	00766	01576	02185	02289	02439	03094	03151	03990	04174
04278	04350	05203	05868	06163	06370	06729	06876	07465	08701	08814
09234	09270	09556								

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PRIME      41
   00703  00784  01015  01221  01680  02040  02109  02236  02773  02794  02878
   03466  04774  05061  06049  06981  08338  08515  09879
PRIME      43
   04060  05890  07905  08178  09823
PRIME      47
   02395  02535  03255  04168  04510  07294  07413  09138  09481
PRIME      53
   09619  09676
PRIME      59
   08268
PRIME      61
   03864  04473

   00000  00001  00003
```

TABLE [IX]

S.P.S. Program to Test the Non-squareness of G_n

```
1010       DORG402
1020 PRIME DSB 2,24
1030 Q     DS  101
1040 B     DS  10051
1050 G     DS  2
1060 AR    DSB 2,10001
1070 M     DS  2
1080 P     DS  2
1090 W     DS  2
1100 TP    DS  2
1110 TEMP  DS  5
1120 N     DS  5
1130 U     DS  2
1140 UB    DS  5
1150 LIM   DS  2
1160 ADD   DS  5
1170 J     DS  5
1180 K     DS  5
1190 STOR  DS  3
1200 PER   DS  5
1201 ALPHA DS  2
2010 D     DS  5
2020 BETA  DAC 50,PRIME
2030       DAC 30,
2040 ZERO  DC  50,
2050       DC  1,@
2060 BLANK DNB 1
2070       DNB 50
2080       DNB 29
2090       DC  1,@
2100 BET   DS  1
2110       DS  80
2120 START RNPTU-1
```

```
2130          RNPTPRIME-1
2140          TFM *+30,G
2150          AM  *+18,2
2160   S13    TFM G,1,10
2170          TF  *+30,S13+6
2180          AM  *+18,2
2190          TFM G,1,10
2200          TFM *+23,PRIME
3010   S23    TF  P,PRIME
3020          BTM SUBR
3030          TFM J,
3040          TFM S14+11,G
3050          AM  S14+11,2
3060          TFM *+35,Q
3070   S14    S   *+23,G
3080          BNF S15,Q
3090          TFM *+30,B
3100          S   *+18,J
3110          SF  B
3120   S15    AM  J,1
3130          C   J,PER
3140          BNH S14-24
3150          TFM J,
3160          TFM *+23,B
3170   S18    BNF S17,B
3180          TF  D,J
3190   S16    A   D,PER
3200          AM  D,1
4010          C   D,UB
4020          BH  S17
4030          TFM *+30,B
4040          S   *+18,D
4050          SF  B
```

```
4060          B    S16
4070   S17    AM   J,1
4080          SM   S18+11,1
4090          C    J,PER
4100          BNH  S18
4110          TNF  BETA+24,P
4120          TNF  BETA+50,PER
4130          WACDBETA
4140          TFM  J,
4150          SM   J,1
4160          TFM  S21+11,B+1
4170          TR   BET,BLANK
4180          TFM  S20+18,BET
4190   S19    AM   J,1
4200          C    J,UB
5010          BH   S22
5020          SM   *+23,1
5030   S21    BNF  S20,B
5040          B    S19
5050   S20    AM   *+18,7
5060          TF   BET,J
5070          TF   *+30,S20+18
5080          SM   *+18,4
5090          CF   BET
5100          CM   S20+18,BET+73
5110          BNH  S19
5120          WNCDBET
5130          B    S19-24
5140   S22    WNCDBET
5150          BC1  S31
5160          SM   U,1,10
5170          CM   U,,10
5180          BZ   OUTP
```

```
5190          AM   S23+11,2
5200          TF   P,S23+11,11
6010          TNF  BETA+24,P
6020          BTM  SUBR
6050          TNF  BETA+50,PER
6060          WACDBETA
6070          TF   D,PER
6080          AM   D,1
6090          TR   BET,BLANK
6100          TFM  S29+6,BET
6110          TFM  J,
6120          TFM  *+23,B
6130   S26    BNF  S27,B
6140          LD   99,J
6150          D    95,D
6160          TF   K,99
6170          TFM  S30+11,G
6180          A    S30+11,K
6190          A    S30+11,K
6200          AM   S30+11,2
7010          TFM  S30+23,Q
7020   S30    S    S30+23,G
7030          BNF  S28,Q
7040   S27    AM   J,1
7050          C    J,UB
7060          BH   S22
7070          SM   S26+11,1
7080          B    S26
7090   S28    TFM  *+30,B
7100          S    *+18,J
7110          CF   B
7120          AM   *+18,7
7130   S29    TF   BET,J
```

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7131       TF   *+30,S29+6
7140       SM   *+18,4
7150       CF   BET
7160       CM   S29+6,BET+73
7170       BNH S27
7180       WNCDBET
7190       TR   BET,BLANK
7200       TFM S29+6,BET
8010       B    S27
8020  S31  TFM S32+11,B
8030       TR   BET,BLANK
8040       TFM S33+6,BET
8050  S32  BNF S34,B
8060       TFM J,B
8070       S    J,S32+11
8080       AM   *+18,7
8090  S33  TF   BET,J
8100       TF   *+30,S33+6
8110       SM   *+18,4
8120       CF   BET
8130       CM   S33+6,BET+73
8140       BNH S34
8150       WNCDBET
8160       SM   S32+11,1
8170       CM   S32+11,B-10000
8180       BNL S31+12
8190  S41  BNC3S42
8191       TFM S40+6,B-10000
8192  S40  TR   ,ZERO-48
8193       AM   S40+6,50
8195       CM   S40+6,B
8196       BNH S40
8197  S42  H
```

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 8200  S34   SM  S32+11,1
 9010        CM  S32+11,B-10000
 9020        BNL S32
 9030        WNCDBET
 9040        B   S41
 9050  OUTP  BNC2S31
 9060        RNPTU-1
 9070        RNPTPRIME-1
 9080        TFM S23+11,PRIME
 9090        B   S22+24
U0010  SUBR  TFM M,,10
U0020        TF  LIM,P
U0030        SM  LIM,2,10
U0040  S5    TF  N,M
U0050        TFM M,1,10
U0060        TFM ADD,
U0070  S1    TFM STAT1+23,G
U0080        TF  TEMP,ADD
U0090        A   TEMP,N
U0100        AM  TEMP,1
U0110        A   STAT1+23,TEMP
U0120        A   STAT1+23,TEMP
U0130        TF  STAT1+11,STAT1+23
U0140        AM  STAT1+11,2
U0160        A   ADD,P
U0170        S   ADD,M
U0180        TF  TEMP,ADD
U0190        TFM S2+6,G
U0200        A   TEMP,N
U1010        AM  TEMP,1
U1020        A   S2+6,TEMP
U1030        A   S2+6,TEMP
U1040  STAT1 TF  STOR,G
```

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U1050        A    STOR,G
U1060        LD   99,STOR
U1070        D    98,P
U1080   S2   TF   G,99
U1090        CM   N,,10
U1100        BZ   S3
U1110        AM   M,1,10
U1120        SM   N,1,10
U1130        B    S1
U1140   S3   TF   S4+11,S2+6
U1150        TFM  S4+6,G
U1160        A    S4+6,M
U1170        A    S4+6,M
U1180        AM   S4+6,4
U1190   S4   TF   G,G
U1200        C    M,LIM
U2010        BNE  S5
12020        TFM  N,
U2030   S9   TF   ALPHA,P
12040        SM   ALPHA,1,10
U2050        TFM  S6+11,G
U2060        A    S6+11,N
U2070        A    S6+11,N
U2080        AM   S6+11,2
U2090        TF   S6+23,S6+11
U2100        AM   S6+23,2
U2110        TF   S8+6,S6+11
U2120        A    S8+6,P
U2130        A    S8+6,P
U2140   S6   TF   STOR,G
U2150        A    STOR,G
U2160        LD   99,STOP
U2170        D    98,P
```

```
U2180  S8     TF   G,99
12190         C    N,ALPHA
12200         BNL  S10
13010  S12    AM   N,1
U3020         C    N,UB
U3030         BNH  S9
03040         TF   PER,UB
U3050         B    SUB2
U3060  S10    TFM  S11+6,G
U3070         A    S11+6,ALPHA
U3080         A    S11+6,ALPHA
U3090         AM   S11+6,2
U3100         TF   S11+11,S11+6
U3110         A    S11+11,N
U3120         A    S11+11,N
U3130         AM   S11+11,2
U3140  S11    C    G,G
U3150         BNE  S12
U3160         SM   ALPHA,1,10
U3170         CM   ALPHA,,10
U3180         BNL  S10
U3190         TF   PER,N
U3200  SUB2   TF   TP,P
U4010         SM   TP,1,10
U4020         MM   TP,5,10
U4030         SF   97
U4040         TF   TP,98
U4050         TFM  W,,10
U4060         TFM  CLEAR+6,Q-100
U4070  CLEAR  TR   ,ZERO-48
U4080         AM   CLEAR+6,50
U4090         CM   CLEAR+6,Q
U4100         BNH  CLEAR
```

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U4110          SF   Q
U4120   INCW   AM   W,1,10
U4130          C    W,TP
U4140          BNH  *+24
U4150          BB
U4160          M    W,W
U4170          SF   96
U4180          TF   TEMP,99
U4190          LD   99,TEMP
U4200          D    98,P
U5010          TF   TEMP,99
U5020          TFM  SET+6,Q
15030          S    SET+6,TEMP
U5040   SET    SF   Q
U5050          B    INCW
15060          DENDSTART
```

TABLE [X]

Results of Machine Computation with the Program of TABLE IX

PRIMEZ 03 00012

00002	00003	00006	00015	00016	00019	00028	00029	00032	00041	00042
00045	00054	00055	00058	00067	00068	00071	00080	00081	00084	00093
00094	00097	00106	00107	00110	00119	00120	00123	00132	00133	00136
00145	00146	00149	00158	00159	00162	00171	00172	00175	00184	00185
00188	00197	00198	00201	00210	00211	00214	00223	00224	00227	00236
00237	00240	00249	00250	00253	00262	00263	00266	00275	00276	00279
00288	00289	00292	00301	00302	00305	00314	00315	00318	00327	00328
00331	00340	00341	00344	00353	00354	00357	00366	00367	00370	00379
00380	00383	00392	00393	00396	00405	00406	00409	00418	00419	00422
00431	00432	00435	00444	00445	00448	00457	00458	00461	00470	00471
00474	00483	00484	00487	00496	00497	00500	00509	00510	00513	00522
00523	00526	00535	00536	00539	00548	00549	00552	00561	00562	00565
00574	00575	00578	00587	00588	00591	00600	00601	00604	00613	00614
00617	00626	00627	00630	00639	00640	00643	00652	00653	00656	00665
00666	00669	00678	00679	00682	00691	00692	00695	00704	00705	00708
00717	00718	00721	00730	00731	00734	00743	00744	00747	00756	00757
00760	00769	00770	00773	00782	00783	00786	00795	00796	00799	00808
00809	00812	00821	00822	00825	00834	00835	00838	00847	00848	00851
00860	00861	00864	00873	00874	00877	00886	00887	00890	00899	00900
00903	00912	00913	00916	00925	00926	00929	00938	00939	00942	00951
00952	00955	00964	00965	00968	00977	00978	00981	00990	00991	00994
01003	01004	01007	01016	01017	01020	01029	01030	01033	01042	01043
01046	01055	01056	01059	01068	01069	01072	01081	01082	01085	01094
01095	01098	01107	01108	01111	01120	01121	01124	01133	01134	01137
01146	01147	01150	01159	01160	01163	01172	01173	01176	01185	01186
01189	01198	01199	01202	01211	01212	01215	01224	01225	01228	01237
01238	01241	01250	01251	01254	01263	01264	01267	01276	01277	01280
01289	01290	01293	01302	01303	01306	01315	01316	01319	01328	01329
01332	01341	01342	01345	01354	01355	01358	01367	01368	01371	01380
01381	01384	01393	01394	01397	01406	01407	01410	01419	01420	01423
01432	01433	01436	01445	01446	01449	01458	01459	01462	01471	01472
01475	01484	01485	01488	01497	01498	01501	01510	01511	01514	01523

01524	01527	01536	01537	01540	01549	01550	01553	01562	01563	01566
01575	01576	01579	01588	01589	01592	01601	01602	01605	01614	01615
01618	01627	01628	01631	01640	01641	01644	01653	01654	01657	01666
01667	01670	01679	01680	01683	01692	01693	01696	01705	01706	01709
01718	01719	01722	01731	01732	01735	01744	01745	01748	01757	01758
01761	01770	01771	01774	01783	01784	01787	01796	01797	01800	01809
01810	01813	01822	01823	01826	01835	01836	01839	01848	01849	01852
01861	01862	01865	01874	01875	01878	01887	01888	01891	01900	01901
01904	01913	01914	01917	01926	01927	01930	01939	01940	01943	01952
01953	01956	01965	01966	01969	01978	01979	01982	01991	01992	01995
02004	02005	02008	02017	02018	02021	02030	02031	02034	02043	02044
02047	02056	02057	02060	02069	02070	02073	02082	02083	02086	02095
02096	02099	02108	02109	02112	02121	02122	02125	02134	02135	02138
02147	02148	02151	02160	02161	02164	02173	02174	02177	02186	02187
02190	02199	02200	02203	02212	02213	02216	02225	02226	02229	02238
02239	02242	02251	02252	02255	02264	02265	02268	02277	02278	02281
02290	02291	02294	02303	02304	02307	02316	02317	02320	02329	02330
02333	02342	02343	02346	02355	02356	02359	02368	02369	02372	02381
02382	02385	02394	02395	02398	02407	02408	02411	02420	02421	02424
02433	02434	02437	02446	02447	02450	02459	02460	02463	02472	02473
02476	02485	02486	02489	02498	02499	02502	02511	02512	02515	02524
02525	02528	02537	02538	02541	02550	02551	02554	02563	02564	02567
02576	02577	02580	02589	02590	02593	02602	02603	02606	02615	02616
02619	02628	02629	02632	02641	02642	02645	02654	02655	02658	02667
02668	02671	02680	02681	02684	02693	02694	02697	02706	02707	02710
02719	02720	02723	02732	02733	02736	02745	02746	02749	02758	02759
02762	02771	02772	02775	02784	02785	02788	02797	02798	02801	02810
02811	02814	02823	02824	02827	02836	02837	02840	02849	02850	02853
02862	02863	02866	02875	02876	02879	02888	02889	02892	02901	02902
02905	02914	02915	02918	02927	02928	02931	02940	02941	02944	02953
02954	02957	02966	02967	02970	02979	02980	02983	02992	02993	02996
03005	03006	03009	03018	03019	03022	03031	03032	03035	03044	03045
03048	03057	03058	03061	03070	03071	03074	03083	03084	03087	03096

03097	03100	03109	03110	03113	03122	03123	03126	03135	03136	03139
03148	03149	03152	03161	03162	03165	03174	03175	03178	03187	03188
03191	03200	03201	03204	03213	03214	03217	03226	03227	03230	03239
03240	03243	03252	03253	03256	03265	03266	03269	03278	03279	03282
03291	03292	03295	03304	03305	03308	03317	03318	03321	03330	03331
03334	03343	03344	03347	03356	03357	03360	03369	03370	03373	03382
03383	03386	03395	03396	03399	03408	03409	03412	03421	03422	03425
03434	03435	03438	03447	03448	03451	03460	03461	03464	03473	03474
03477	03486	03487	03490	03499	03500	03503	03512	03513	03516	03525
03526	03529	03538	03539	03542	03551	03552	03555	03564	03565	03568
03577	03578	03581	03590	03591	03594	03603	03604	03607	03616	03617
03620	03629	03630	03633	03642	03643	03646	03655	03656	03659	03668
03669	03672	03681	03682	03685	03694	03695	03698	03707	03708	03711
03720	03721	03724	03733	03734	03737	03746	03747	03750	03759	03760
03763	03772	03773	03776	03785	03786	03789	03798	03799	03802	03811
03812	03815	03824	03825	03828	03837	03838	03841	03850	03851	03854
03863	03864	03867	03876	03877	03880	03889	03890	03893	03902	03903
03906	03915	03916	03919	03928	03929	03932	03941	03942	03945	03954
03955	03958	03967	03968	03971	03980	03981	03984	03993	03994	03997
04006	04007	04010	04019	04020	04023	04032	04033	04036	04045	04046
04049	04058	04059	04062	04071	04072	04075	04084	04085	04088	04097
04098	04101	04110	04111	04114	04123	04124	04127	04136	04137	04140
04149	04150	04153	04162	04163	04166	04175	04176	04179	04188	04189
04192	04201	04202	04205	04214	04215	04218	04227	04228	04231	04240
04241	04244	04253	04254	04257	04266	04267	04270	04279	04280	04283
04292	04293	04296	04305	04306	04309	04318	04319	04322	04331	04332
04335	04344	04345	04348	04357	04358	04361	04370	04371	04374	04383
04384	04387	04396	04397	04400	04409	04410	04413	04422	04423	04426
04435	04436	04439	04448	04449	04452	04461	04462	04465	04474	04475
04478	04487	04488	04491	04500	04501	04504	04513	04514	04517	04526
04527	04530	04539	04540	04543	04552	04553	04556	04565	04566	04569
04578	04579	04582	04591	04592	04595	04604	04605	04608	04617	04618
04621	04630	04631	04634	04643	04644	04647	04656	04657	04660	04669

04670	04673	04682	04683	04686	04695	04696	04699	04708	04709	04712
04721	04722	04725	04734	04735	04738	04747	04748	04751	04760	04761
04764	04773	04774	04777	04786	04787	04790	04799	04800	04803	04812
04813	04816	04825	04826	04829	04838	04839	04842	04851	04852	04855
04864	04865	04868	04877	04878	04881	04890	04891	04894	04903	04904
04907	04916	04917	04920	04929	04930	04933	04942	04943	04946	04955
04956	04959	04968	04969	04972	04981	04982	04985	04994	04995	04998
05007	05008	05011	05020	05021	05024	05033	05034	05037	05046	05047
05050	05059	05060	05063	05072	05073	05076	05085	05086	05089	05098
05099	05102	05111	05112	05115	05124	05125	05128	05137	05138	05141
05150	05151	05154	05163	05164	05167	05176	05177	05180	05189	05190
05193	05202	05203	05206	05215	05216	05219	05228	05229	05232	05241
05242	05245	05254	05255	05258	05267	05268	05271	05280	05281	05284
05293	05294	05297	05306	05307	05310	05319	05320	05323	05332	05333
05336	05345	05346	05349	05358	05359	05362	05371	05372	05375	05384
05385	05388	05397	05398	05401	05410	05411	05414	05423	05424	05427
05436	05437	05440	05449	05450	05453	05462	05463	05466	05475	05476
05479	05488	05489	05492	05501	05502	05505	05514	05515	05518	05527
05528	05531	05540	05541	05544	05553	05554	05557	05566	05567	05570
05579	05580	05583	05592	05593	05596	05605	05606	05609	05618	05619
05622	05631	05632	05635	05644	05645	05648	05657	05658	05661	05670
05671	05674	05683	05684	05687	05696	05697	05700	05709	05710	05713
05722	05723	05726	05735	05736	05739	05748	05749	05752	05761	05762
05765	05774	05775	05778	05787	05788	05791	05800	05801	05804	05813
05814	05817	05826	05827	05830	05839	05840	05843	05852	05853	05856
05865	05866	05869	05878	05879	05882	05891	05892	05895	05904	05905
05908	05917	05918	05921	05930	05931	05934	05943	05944	05947	05956
05957	05960	05969	05970	05973	05982	05983	05986	05995	05996	05999
06008	06009	06012	06021	06022	06025	06034	06035	06038	06047	06048
06051	06060	06061	06064	06073	06074	06077	06086	06087	06090	06099
06100	06103	06112	06113	06116	06125	06126	06129	06138	06139	06142
06151	06152	06155	06164	06165	06168	06177	06178	06181	06190	06191
06194	06203	06204	06207	06216	06217	06220	06229	06230	06233	06242

06243	06246	06255	06256	06259	06268	06269	06272	06281	06282	06285
06294	06295	06298	06307	06308	06311	06320	06321	06324	06333	06334
06337	06346	06347	06350	06359	06360	06363	06372	06373	06376	06385
06386	06389	06398	06399	06402	06411	06412	06415	06424	06425	06428
06437	06438	06441	06450	06451	06454	06463	06464	06467	06476	06477
06480	06489	06490	06493	06502	06503	06506	06515	06516	06519	06528
06529	06532	06541	06542	06545	06554	06555	06558	06567	06568	06571
06580	06581	06584	06593	06594	06597	06606	06607	06610	06619	06620
06623	06632	06633	06636	06645	06646	06649	06658	06659	06662	06671
06672	06675	06684	06685	06688	06697	06698	06701	06710	06711	06714
06723	06724	06727	06736	06737	06740	06749	06750	06753	06762	06763
06766	06775	06776	06779	06788	06789	06792	06801	06802	06805	06814
06815	06818	06827	06828	06831	06840	06841	06844	06853	06854	06857
06866	06867	06870	06879	06880	06883	06892	06893	06896	06905	06906
06909	06918	06919	06922	06931	06932	06935	06944	06945	06948	06957
06958	06961	06970	06971	06974	06983	06984	06987	06996	06997	07000
07009	07010	07013	07022	07023	07026	07035	07036	07039	07048	07049
07052	07061	07062	07065	07074	07075	07078	07087	07088	07091	07100
07101	07104	07113	07114	07117	07126	07127	07130	07139	07140	07143
07152	07153	07156	07165	07166	07169	07178	07179	07182	07191	07192
07195	07204	07205	07208	07217	07218	07221	07230	07231	07234	07243
07244	07247	07256	07257	07260	07269	07270	07273	07282	07283	07286
07295	07296	07299	07308	07309	07312	07321	07322	07325	07334	07335
07338	07347	07348	07351	07360	07361	07364	07373	07374	07377	07386
07387	07390	07399	07400	07403	07412	07413	07416	07425	07426	07429
07438	07439	07442	07451	07452	07455	07464	07465	07468	07477	07478
07481	07490	07491	07494	07503	07504	07507	07516	07517	07520	07529
07530	07533	07542	07543	07546	07555	07556	07559	07568	07569	07572
07581	07582	07585	07594	07595	07598	07607	07608	07611	07620	07621
07624	07633	07634	07637	07646	07647	07650	07659	07660	07663	07672
07673	07676	07685	07686	07689	07698	07699	07702	07711	07712	07715
07724	07725	07728	07737	07738	07741	07750	07751	07754	07763	07764
07767	07776	07777	07780	07789	07790	07793	07802	07803	07806	07815

07816	07819	07828	07829	07832	07841	07842	07845	07854	07855	07858
07867	07868	07871	07880	07881	07884	07893	07894	07897	07906	07907
07910	07919	07920	07923	07932	07933	07936	07945	07946	07949	07958
07959	07962	07971	07972	07975	07984	07985	07988	07997	07998	08001
08010	08011	08014	08023	08024	08027	08036	08037	08040	08049	08050
08053	08062	08063	08066	08075	08076	08079	08088	08089	08092	08101
08102	08105	08114	08115	08118	08127	08128	08131	08140	08141	08144
08153	08154	08157	08166	08167	08170	08179	08180	08183	08192	08193
08196	08205	08206	08209	08218	08219	08222	08231	08232	08235	08244
08245	08248	08257	08258	08261	08270	08271	08274	08283	08284	08287
08296	08297	08300	08309	08310	08313	08322	08323	08326	08335	08336
08339	08348	08349	08352	08361	08362	08365	08374	08375	08378	08387
08388	08391	08400	08401	08404	08413	08414	08417	08426	08427	08430
08439	08440	08443	08452	08453	08456	08465	08466	08469	08478	08479
08482	08491	08492	08495	08504	08505	08508	08517	08518	08521	08530
08531	08534	08543	08544	08547	08556	08557	08560	08569	08570	08573
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PRIMEZ 07 10000

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09136	09138	09147	09150	09152	09162	09164	09179	09183	09188	09195
09196	09205	09212	09213	09217	09222	09228	09242	09252	09256	09257
09260	09261	09264	09265	09268	09269	09289	09294	09295	09296	09299
09300	09315	09317	09320	09321	09328	09329	09343	09347	09357	09361
09367	09369	09380	09393	09400	09406	09407	09411	09422	09429	09450
09451	09452	09463	09468	09474	09481	09486	09487	09494	09498	09499
09503	09504	09507	09513	09515	09521	09527	09530	09534	09536	09537
09542	09559	09568	09573	09575	09580	09590	09591	09593	09607	09628
09629	09640	09645	09659	09660	09664	09672	09676	09683	09685	09689
09698	09707	09708	09719	09720	09731	09734	09735	09744	09745	09748
09749	09757	09758	09759	09761	09762	09763	09764	09767	09772	09775
09780	09783	09785	09786	09809	09811	09813	09820	09824	09825	09827
09828	09832	09833	09837	09841	09849	09853	09862	09863	09864	09874
09875	09885	09888	09891	09901	09903	09905	09914	09917	09919	09926
09927	09940	09950	09959	09965	09969	09970	09983	09984	09985	09988
09989	09992	09993	09997							

PRIMEZ 11 10000

00011	00023	00038	00039	00043	00050	00079	00102	00108	00113	00114
00127	00135	00141	00147	00151	00173	00180	00196	00202	00229	00243
00251	00264	00280	00287	00332	00348	00358	00362	00373	00376	00385
00387	00408	00414	00420	00427	00428	00450	00453	00476	00488	00494
00498	00499	00501	00503	00505	00516	00519	00529	00531	00545	00547
00554	00555	00563	00581	00592	00593	00631	00661	00670	00672	00688
00693	00698	00726	00738	00766	00771	00778	00830	00831	00837	00845
00891	00895	00896	00897	00920	00927	00943	00960	00974	00983	00989
00998	01002	01021	01022	01067	01073	01074	01078	01084	01103	01110
01129	01136	01153	01166	01170	01171	01179	0120[illegible]	01207	01233	01242
01248	01262	01273	01275	01294	01300	01314	01323	01326	01338	01340
01344	01352	01370	01373	01379	01385	01386	01402	01403	01409	01412
01430	01450	01453	01464	01486	01494	01502	01513	01532	01538	01539
01543	01547	01551	01557	01559	01565	01580	01583	01600	01632	01634

01643	01647	01658	01665	01674	01675	01677	01678	01681	01688	01697
01701	01717	01727	01728	01743	01749	01763	01766	01773	01780	01785
01790	01798	01803	01830	01831	01837	01850	01855	01866	01879	01881
01883	01892	01896	01915	01919	01925	01938	01954	01968	01970	01973
01976	01984	01985	01988	01999	02001	02010	02015	02019	02022	02027
02038	02054	02061	02063	02065	02089	02090	02097	02101	02123	02130
02133	02143	02152	02154	02183	02204	02207	02211	02217	02232	02241
02245	02250	02262	02269	02272	02275	02280	02283	02287	02288	02292
02299	02300	02332	02338	02341	02354	02366	02380	02386	02389	02392
02435	02439	02442	02451	02458	02475	02482	02490	02494	02505	02507
02508	02513	02522	02523	02553	02561	02562	02571	02579	02584	02591
02600	02612	02618	02630	02631	02635	02636	02643	02652	02653	02660
02662	02664	02669	02670	02675	02688	02696	02700	02705	02715	02716
02729	02730	02747	02753	02764	02795	02799	02803	02819	02835	02838
02844	02846	02856	02859	02860	02872	02874	02877	02878	02882	02883
02884	02885	02886	02890	02891	02898	02899	02933	02935	02943	02959
02963	02973	02974	02981	02995	02999	03004	03012	03016	03020	03026
03043	03047	03050	03051	03054	03060	03065	03067	03069	03094	03104
03111	03127	03132	03134	03141	03156	03163	03167	03169	03170	03172
03194	03202	03205	03207	03220	03232	03237	03245	03246	03251	03273
03297	03300	03325	03326	03327	03345	03348	03353	03362	03365	03378
03385	03387	03393	03411	03415	03424	03431	03439	03441	03442	03463
03485	03492	03497	03508	03509	03514	03517	03519	03522	03527	03528
03534	03537	03550	03557	03572	03574	03597	03600	03605	03614	03640
03641	03654	03657	03658	03664	03667	03678	03687	03689	03705	03742
03745	03752	03755	03775	03807	03817	03822	03833	03840	03845	03853
03858	03866	03875	03886	03895	03908	03920	03922	03931	03933	03940
03961	03962	03990	03999	04014	04017	04047	04052	04054	04056	04060
04069	04078	04081	04082	04089	04092	04099	04122	04125	04141	04142
04161	04170	04183	04185	04199	04204	04220	04224	04232	04250	04259
04262	04276	04278	04282	04288	04289	04291	04297	04301	04304	04316
04328	04341	04352	04359	04393	04404	04434	04443	04453	04459	04468
04473	04480	04483	04493	04497	04498	04505	04509	04522	04557	04567

04570	04584	04589	04593	04598	04609	04615	04616	04627	04653	04655
04661	04662	04667	04671	04676	04697	04701	04714	04718	04720	04736
04740	04753	04765	04779	04796	04807	04817	04827	04835	04841	04843
04856	04862	04880	04910	04918	04922	04924	04926	04934	04974	04975
04997	05001	05016	05022	05031	05039	05048	05053	05058	05064	05070
05075	05078	05079	05081	05082	05097	05105	05106	05117	05119	05134
05135	05147	05149	05155	05159	05181	05188	05191	05196	05217	05220
05224	05225	05227	05233	05246	05256	05261	05265	05283	05300	05337
05338	05340	05342	05354	05355	05356	05364	05391	05393	05407	05415
05416	05434	05435	05443	05448	05455	05457	05464	05467	05478	05482
05485	05493	05499	05506	05524	05530	05537	05550	05574	05581	05589
05594	05602	05614	05629	05637	05647	05652	05654	05660	05665	05688
05692	05698	05699	05705	05728	05731	05742	05754	05755	05756	05758
05760	05767	05784	05803	05819	05821	05825	05850	05854	05875	05877
05890	05893	05919	05920	05923	05924	05927	05928	05948	05950	05958
05961	05963	05972	05974	05988	05994	05997	05998	06003	06007	06010
06014	06024	06027	06040	06042	06045	06046	06055	06057	06065	06088
06098	06102	06109	06128	06140	06158	06167	06171	06174	06175	06180
06189	06192	06209	06215	06218	06223	06248	06249	06258	06265	06271
06280	06293	06296	06305	06315	06316	06326	06355	06356	06362	06364
06367	06369	06403	06427	06444	06449	06468	06469	06471	06473	06482
06485	06536	06537	06550	06559	06561	06562	06563	06565	06575	06587
06595	06596	06603	06615	06634	06643	06647	06651	06652	06656	06668
06670	06674	06676	06680	06689	06700	06703	06731	06732	06743	06744
06746	06747	06758	06764	06767	06791	06795	06819	06835	06838	06848
06859	06861	06862	06869	06874	06910	06913	06921	06924	06927	06941
06949	06956	06962	06969	06973	06977	06985	06988	07006	07012	07027
07029	07066	07067	07073	07079	07083	07092	07107	07108	07129	07136
07138	07144	07176	07180	07193	07196	07199	07214	07216	07232	07233
07239	07245	07261	07276	07280	07290	07307	07326	07340	07342	07346
07355	07368	07376	07381	07391	07405	07414	07421	07423	07428	07435
07443	07448	07457	07461	07470	07498	07502	07506	07512	07521	07536
07550	07557	07558	07567	07577	07584	07588	07599	07610	07617	07618

07619	07627	07629	07645	07657	07671	07674	07680	07681	07683	07688
07691	07695	07697	07703	07708	07717	07719	07740	07745	07746	07753
07755	07762	07795	07797	07799	07800	07814	07818	07825	07844	07847
07859	07874	07882	07909	07918	07938	07944	07956	07968	07977	07978
07990	07991	08004	08025	08031	08035	08045	08047	08051	08058	08098
08099	08107	08112	08117	08119	08124	08125	08136	08139	08142	08152
08155	08158	08177	08201	08221	08224	08229	08230	08233	08263	08265
08273	08294	08302	08306	08308	08311	08312	08345	08371	08383	08410
08415	08422	08436	08441	08459	08464	08475	08500	08527	08532	08535
08539	08559	08572	08576	08578	08579	08587	08588	08590	08602	08618
08628	08636	08654	08658	08659	08676	08684	08705	08710	08718	08730
08746	08749	08758	08770	08785	08787	08789	08792	08795	08799	08822
08823	08825	08826	08831	08834	08836	08847	08852	08854	08864	08878
08889	08893	08905	08906	08909	08918	08926	08930	08939	08944	08957
08962	08979	08981	08982	08994	09001	09005	09007	09013	09019	09020
09023	09027	09030	09042	09043	09056	09068	09072	09085	09087	09092
09094	09107	09112	09121	09122	09127	09130	09135	09139	09146	09148
09156	09166	09178	09202	09203	09204	09211	09221	09226	09235	09241
09243	09250	09253	09263	09267	09270	09279	09282	09292	09302	09303
09304	09312	09341	09342	09348	09359	09368	09370	09372	09396	09399
09421	09436	09439	09442	09455	09464	09465	09472	09484	09497	09500
09502	09511	09514	09523	09538	09539	09549	09552	09556	09562	09588
09606	09620	09633	09638	09647	09650	09663	09669	09681	09682	09694
09699	09711	09729	09738	09741	09770	09771	09776	09793	09794	09799
09800	09801	09803	09819	09822	09826	09829	09835	09845	09848	09866
09879	09889	09893	09902	09910	09913	09916	09928	09932	09933	09942
09945	09966	09976	09994	09998						

PRIMEZ 13 10000

00004	00018	00021	00056	00072	00083	00100	00134	00143	00155	00181
00190	00216	00219	00231	00245	00256	00269	00286	00294	00297	00304
00322	00326	00330	00335	00345	00355	00359	00369	00384	00388	00413
00421	00502	00557	00638	00673	00676	00677	00699	00707	00722	00733
00742	00781	00784	00792	00815	00816	00824	00826	00862	00881	00883

00888	00894	00923	00930	00946	00966	00997	01000	01018	01019	01044
01050	01057	01079	01142	01144	01157	01158	01164	01167	01197	01203
01208	01210	01214	01217	01256	01258	01272	01282	01291	01308	01309
01311	01322	01337	01356	01374	01383	01437	01440	01451	01479	01490
01505	01521	01596	01610	01612	01616	01619	01625	01645	01690	01703
01704	01708	01724	01752	01876	01880	01885	01894	01897	01910	01916
01920	01924	01933	01945	01947	01950	01955	01975	01993	02029	02037
02058	02067	02072	02078	02091	02102	02119	02132	02141	02192	02193
02221	02224	02302	02324	02328	02340	02344	02364	02367	02370	02399
02400	02413	02426	02445	02453	02464	02465	02470	02527	02546	02560
02568	02572	02581	02594	02604	02666	02677	02682	02702	02714	02721
02734	02765	02770	02780	02782	02804	02806	02816	02839	02887	02903
02906	02911	02956	03008	03021	03024	03042	03046	03076	03077	03095
03102	03120	03121	03145	03147	03181	03209	03233	03250	03288	03340
03355	03358	03364	03381	03402	03428	03459	03469	03472	03507	03523
03532	03543	03544	03546	03561	03585	03608	03619	03622	03625	03634
03637	03662	03697	03699	03729	03738	03744	03762	03793	03794	03805
03808	03814	03872	03892	03894	03905	03923	03959	03998	04018	04021
04044	04048	04067	04126	04128	04173	04181	04191	04216	04239	04260
04268	04271	04295	04300	04321	04324	04338	04342	04356	04388	04401
04441	04444	04445	04447	04492	04495	04499	04502	04503	04507	04510
04519	04523	04549	04583	04610	04614	04654	04684	04690	04707	04710
04713	04730	04758	04785	04793	04828	04844	04848	04870	04873	04884
04887	04889	04896	04906	04911	04914	04921	04923	04952	04964	04973
04980	05015	05052	05107	05122	05133	05169	05174	05178	05182	05205
05207	05214	05231	05234	05251	05275	05276	05286	05298	05299	05303
05308	05331	05365	05377	05379	05387	05394	05404	05412	05426	05521
05534	05535	05560	05563	05576	05595	05601	05625	05663	05668	05686
05691	05702	05703	05704	05708	05714	05715	05745	05764	05781	05790
05797	05809	05815	05833	05835	05845	05851	05857	05870	05932	05942
05965	05966	05968	06005	06054	06084	06135	06144	06172	06185	06201
06219	06236	06244	06252	06263	06274	06283	06304	06327	06339	06351
06378	06379	06410	06458	06486	06509	06513	06524	06534	06578	06583

06611	06617	06621	06622	06639	06669	06681	06687	06702	06704	06713
06725	06739	06765	06781	06782	06790	06821	06829	06836	06876	06890
06897	06904	06916	06946	06952	06953	06959	06964	06978	06982	07005
07007	07016	07030	07096	07097	07110	07141	07145	07151	07164	07197
07219	07240	07265	07267	07277	07285	07292	07294	07304	07305	07315
07317	07350	07363	07371	07382	07384	07388	07392	07396	07417	07432
07449	07456	07460	07462	07486	07513	07539	07576	07622	07640	07678
07679	07705	07733	07734	07736	07771	07778	07791	07838	07849	07877
07890	07895	07912	07913	07941	07961	07967	07974	07989	08012	08018
08034	08055	08073	08074	08086	08129	08146	08162	08173	08186	08202
08204	08220	08246	08247	08251	08260	08262	08264	08293	08305	08320
08338	08351	08354	08366	08370	08399	08403	08423	08448	08461	08476
08483	08486	08513	08515	08520	08536	08540	08542	08562	08567	08571
08619	08623	08639	08641	08682	08732	08737	08753	08767	08784	08793
08827	08838	08839	08871	08943	08945	08949	08953	08975	08980	09017
09018	09039	09046	09058	09074	09075	09083	09104	09108	09118	09151
09169	09189	09191	09216	09229	09290	09325	09339	09355	09360	09371
09373	09387	09398	09404	09416	09417	09420	09433	09471	09475	09485
09488	09491	09529	09551	09566	09576	09592	09595	09603	09612	09615
09617	09670	09679	09690	09725	09760	09798	09839	09867	09868	09871
09877	09906	09907	09929	09937	09943	09953	09962	09972		

PRIMEZ 17 10000

00034	00035	00121	00187	00193	00228	00238	00254	00293	00334	00339
00378	00410	00429	00436	00491	00517	00534	00618	00621	00724	00749
00750	00759	00802	00818	00866	00902	00909	00922	00947	00971	01028
01032	01035	01092	01102	01143	01175	01181	01184	01194	01222	01257
01284	01288	01297	01312	01320	01321	01346	01369	01398	01435	01469
01491	01492	01503	01545	01672	01684	01687	01694	01739	01765	01781
01782	01793	01794	01807	01825	01827	01838	01869	02050	02075	02105
02110	02116	02137	02175	02235	02274	02339	02378	02393	02415	02428
02456	02471	02477	02478	02516	02533	02547	02607	02661	02701	02726
02738	02739	02841	02842	02916	02937	02955	02960	03011	03064	03112
03124	03294	03322	03328	03349	03359	03380	03410	03454	03476	03502

03515	03576	03587	03612	03626	03651	03660	03692	03713	03714	03718
03726	03728	03735	03778	03803	03873	03904	03948	03953	03986	04005
04103	04139	04143	04168	04169	04194	04198	04209	04237	04247	04264
04273	04299	04303	04308	04337	04346	04378	04574	04577	04635	04642
04681	04731	04732	04743	04782	04805	04832	04833	04879	04937	04940
04950	04966	05038	05043	05092	05100	05118	05146	05161	05243	05264
05324	05399	05408	05418	05452	05465	05468	05490	05510	05597	05616
05640	05724	05730	05747	05789	05822	05828	05834	05858	05861	05881
05883	05900	05922	05959	05962	06081	06085	06093	06111	06183	06184
06196	06200	06224	06235	06251	06297	06344	06395	06432	06442	06465
06600	06626	06640	06642	06717	06804	06811	06813	06868	06885	06960
06966	06981	07019	07046	07050	07112	07159	07172	07223	07254	07332
07358	07505	07519	07525	07545	07564	07589	07592	07602	07623	07626
07707	07747	07811	07813	07925	07935	07940	07953	07994	08006	08020
08038	08097	08103	08172	08178	08237	08239	08249	08267	08275	08286
08397	08421	08455	08511	08522	08580	08589	08594	08606	08629	08652
08671	08685	08693	08694	08721	08756	08812	08815	08832	08860	08867
08904	08914	08927	08938	08969	09040	09045	09060	09170	09172	09208
09209	09247	09274	09305	09307	09313	09331	09382	09409	09410	09426
09540	09553	09565	09582	09589	09601	09608	09637	09658	09693	09706
09724	09733	09746	09755	09900	09911	09920	09931			

PRIMEZ 19 10000

00103	00109	00157	00179	00247	00317	00433	00447	00528	00662	00714
00751	00758	00789	00791	00820	00893	00948	00961	01013	01090	01135
01191	01204	01246	01279	01443	01495	01506	01573	01597	01608	01630
01669	01726	02003	02052	02081	02103	02127	02150	02197	02214	02228
02310	02312	02319	02331	02404	02443	02492	02637	02774	02845	02871
02897	02922	02930	02968	02987	02988	03013	03015	03027	03059	03091
03289	03301	03352	03453	03456	03479	03501	03547	03575	03680	03684
03740	03832	03846	03881	04012	04063	04152	04235	04381	04406	04559
04586	04638	04645	04666	04704	04750	04801	04818	04888	04989	04993
04996	05003	05009	05018	05040	05084	05113	05226	05249	05311	05312
05321	05335	05348	05390	05395	05494	05512	05577	05588	05608	05677

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   05732  05733  05740  05786  05793  05829  05844  05862  05886  05894  05906
   06188  06237  06435  06582  06625  06631  06755  06796  06826  06903  06939
   06947  07018  07033  07121  07163  07248  07343  07352  07356  07398  07419
   07422  07531  07631  07710  07951  07952  07987  08041  08090  08096  08121
   08171  08199  08200  08236  08241  08327  08364  08402  08472  08501  08528
   08663  08740  08776  08811  08819  08883  08900  08936  09120  09185  09308
   09309  09316  09333  09435  09482  09604  09666  09671  09686  09695  09750
   09915
PRIMEZ     23         10000
   00027  00070  00122  00139  00268  00311  00389  00543  00611  00703  00780
   00785  01099  01174  01180  01187  01310  01349  01457  01530  01756  01799
   01949  01983  01994  02013  02046  02162  02176  02231  02234  02263  02321
   02397  02436  02468  02559  02742  02932  02997  03271  03413  03545  03571
   03618  03623  03834  03882  04015  04108  04386  04767  04778  04821  04837
   04986  04990  04999  05136  05153  05187  05278  05316  05403  05516  05517
   05539  05669  05701  05871  06238  06302  06348  06483  06569  06708  06787
   06845  07040  07068  07331  07482  07485  07766  07779  07926  07937  07986
   08279  08304  08558  08640  08923  08967  08987  09044  09291  09383  09788

PRIMEZ     29         10000
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   06160  06193  06421  06523  06570  06878  06936  06951  06972  07168  07293
   07904  07929  08344  08561  08828  08912  09159  09161  09281  09395  09641
   09702  09768  09855
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   03556  03857  04196  04794  04962  05074  05780  05820  06667  06938  07532
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PRIMEZ     47         10000
   02318
PRIMEZ     53         10000
   03985  08990
PRIMEZ     59         10000

PRIMEZ     61         10000
   00061

   00000  00001
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